EML 4905 Senior Design Project

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BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

Paddle Maker Design and Material Selection

Final Report

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This report is written in partial fulfillment of the requirements in EML 4905. The contents represent the opinion of the authors and not the department of Mechanical and Materials Engineering.

Ethics Statement and Signatures

The work submitted in this project is solely prepared by the team consisting of Nestor Vega, Jorge Ramon, and Orena Danoa, and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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Nomenclature

Symbol	Description	Units
UHMW-PE	Ultra High Molecular Weight Polyethylene	N/A
RBT	Rail Barge and Truck	N/A
RH	Relative Humidity	%
UMT	Universal mechanical Tribology Tester	N/A
PP	Isotactic Polypropylene	N/A
PFD	Percent Fast Decay	%
COF	Coefficient of Friction	N/A
R&D	Research and development	N/A
MR	Millions of Rads (unit of radiation)	MR
USPTO	United States Patent and Trademark Office	N/A
OMM	Optical Magnification Microscope	N/A
LVDT	Linear Variable Differential Transformer	Mm

Abstract

Construction paddles are an important part of the functioning of the "Drag- a- Flight Conveyor", shown in Figure 51 of Appendix D. These conveyors are devices through which powder cement is transported from rail cars to trucks, and the paddles are an essential part of the conveyor system. However, these paddles are made of polyethylene and due to friction against the frame of the machine they wear out quickly and are expensive. Due to the lack of vendors producing the required cut-to-length product, orders usually get back stocked and companies end up paying extra shipping fees and delaying their operations. In an ever expanding society like ours, in which new buildings and houses are constructed every day, this is unacceptable. To improve this situation, a machine that autonomously produces these paddles was developed. The design will allow for the interested companies to produce them in-house with little effort, great efficiency and at a lower price. As part of our project, testing with new, more friction resistive materials, was conducted.

The objective of this project is to find the best material possible for the task at hand - and have the best price to quality ratio in addition to building an autonomous machine to produce these paddles under $2000. The prototype has been designed to employ a combination of several mechanical and electronic systems to accomplish the final output product. The major systems included in the prototype were a drilling system, a cutting mechanism, and a rolling table, all of which are equipped with the appropriate electronic controls.

Some elemental components used in the prototype were bought, and the great majority custom built by the members of the team with the support of the FIU students machine shop, to meet the design requirements. Several friction tests were performed on samples of different

materials to evaluate their performance under conditions similar to those that the paddles are exposed to.

Machine safety rules and regulations were researched extensively to assure that the prototype complies with all standards applicable to such a mechanism. Elemental environmental impact and material recycling plans were explored and are presented below.

After the assembly of the Paddle Maker was completed, several calibration trials were performed, without feeding raw material, to assure that all the systems were behaving properly. Finally, several paddles were fabricated and some final adjustments were done. The machine functioned as expected and the quality of the output paddles was acceptable for the application.

After working on this project during last few months, the main objectives were met. Although satisfactory performance was achieved given the time constraints, several recommendations for future work are stated in Section 10 of this report.

1. Introduction

1.1 Problem Statement

Construction paddles used in a “Drag-a-Flight Conveyor” to load powder cement to incoming trucks are made of polyethylene. Due to friction between the paddles and the metal frame of machine these paddles wear at a relatively fast rate, resulting in unwanted maintenance costs and delays. In addition, paddle orders usually get back stocked due to the lack of producers and the inconsistency of the orders. Expectations are to solve this problem by building a machine to fabricate these paddles. The paddles need to be 37¼” long, ½” thick and 1¾” wide, and with six holes 7/16” in diameter each, spaced by a distance of 5½” in between. The current design of the paddle also features an angle cut in one of the sides to decrease friction. This machine needs to be autonomous and to be able to produce the paddles from a given sheet of raw material. Thus,

the machine will need to first convey the sheet of raw material to the place where by means of a mechanical system the holes will be drilled. Then a circular saw being moved by a stepper motor will do the cutting. Finding a material that is resistant to friction and has a better quality to price ratio than polyethylene is also one of our main objectives.

In addition, our goal will be to modify and strengthen the wear of the current paddle material and test it in the field. The paddles are made of Ultra High Molecular Polyethylene, which has the highest impact strength among all classes of plastic products. Even though it is an extraordinary material for industrial uses in wear and sliding applications, it wears fast in the current function. This can be observed in Figure 50 Appendix C.

1.2 Motivation

Vulcan Materials, Miami Quarry division, offers mining, processing, and distribution services as well as services in sand, gravel and crushed stone retailing. Being the biggest producer of construction aggregates and a top producer of cement in Florida, there is no room for inefficiencies or delays in such a busy operation. That’s why the company is interested in a feasible improvement or solution to this ongoing issue at a cost effective price.

Vulcan operates a “Drag-a-Flight Conveyor” in their Miami Quarry facility that uses polyethylene paddles as a way of transporting the cement powder from the rail cars to the trucks. It usually takes twenty minutes to load a truck with cement powder when the paddles are new; however, when they are worn out, loading time could take up to one hour and twenty minutes. Furthermore, orders of these construction paddles sometimes get back stocked, and subsequently the operation gets delayed due to the inefficiency of the machine. To make matters even worse, these paddles cost $13 dollars apiece, and the conveyor requires 114 of them in order to function properly. It takes about 2 months for the paddles to completely wear out. However, if a more cost

effective material or a more friction resistant material were to be used for this application, efficiency and productivity of the machine could dramatically improve. Moreover, if Vulcan Materials Company were able to produce these paddles independently, the company would not need to buy them anymore, reducing delays to a minimum and boosting its productivity in this part of the facility. This could represent savings of more than ten thousand dollars a year at the Miami Quarry division alone.

Finding the right paddle material and creating a machine that manufactures them, represents a real life solution to a challenging industry problem. There is a need for improvement and we are ready to answer the call with extraordinary effort and dedication while employing knowledge and resources gathered in the course of our engineering studies.

1.3 Literature Survey

Several terms, processes and/or machines, whose understanding is of great importance for the realization of this project, are mentioned throughout the report. Familiarity with these terms was essential for the realization of this project. UHMW-PE (Ultra high Molecular Weight Polyethylene) has one of the highest impact strengths of any thermoplastic and has excellent abrasion resistance, tensile strength, energy absorption, stress resistance, and friction coefficient properties. In this section, an overview of the work done on improving the material's performance by other engineers and scientists will be reviewed.

In addition, there is a need for an in-house machine that can make paddles out of this material. A large UHMW-PE sheet will have to undergo various processes including drilling and cutting. Also means for conveying this raw sheet material need to be incorporated into the machine. A review is conducted here on the brainstorming, and information gathering that lead to the development of such machines over time.

1.3.1 Material

UHMW-PE has become the material of choice in hip and knee joint prostheses in human body. In addition, it is used in many industries where moving and conveying materials presents challenge of finding solution to abrasion, sticking and wear. It is the answer in applications such as drag flights and paddles, side rails and skirt- boards. When compared to other polymers, UHMW-PE possesses superior mechanical toughness and wear-resistance. Despite the success in surgical applications, implanted components produce wear debris, and it is necessary to repeat the surgery and revise the prosthesis. In the case of the Drag Flights application, UHMW-PE paddles wear out quickly after being constantly rubbed against the steel counter face.

Cross-linking of UHMW-PE has been shown to improve its wear resistance by 70% when compared to conventional material. Cross-linking changes the chemical characteristics of the material. It alters the bond between molecular chains, reduces crystalline processes, alters the free radical content of the material and influences the surface properties significantly.

Many experimental tests were done trying to understand the wear behavior and wear debris distribution of UHMW-PE when rubbed against other material. A literature survey of these tests will aid in gathering all the necessary parameters pertaining to our tests. The chosen parameters will be used to test and compare the new improved material to the current one being used by Rail Barge and Truck Company. In addition, it will be tested and compared with UHMW-PE that was exposed to the cross-linking process.

An experiment on friction and wear behavior of nitrogen ion implanted UHMW-PE against ZrO_2 ceramic was studied in China University [1]. The Ball-On-Disc (Figure 1) wear tests were performed using an UMT tester in Campbell, CA. The tester combined linear and

rotary motions in a coordinated manner while taking measurements of tribological parameters such as friction forces, friction coefficient, and wear depth.

Parameters and material used in the study were:

- The material had a disk shape with 10mm thickness, and a diameter of 30mm.
- Roughness of the sample was polished to 0.2 - 0.4µm.
- Ultrasonic bath and acetone as a fluid were used to clean the sample.
- Si_3N_4 balls with 4mm diameter were used to simulate the wear of the artificial joints.
- Wear tests were operated in a 25% plasma solution for 10,000 cycles.
- A Sinusoidal Normal load of 20N - 25N was applied on the Si_3N_4 balls.
- UHMW-PE disk reciprocating at fixed frequency of 0.5 Hz.
- The Si_3N_4 ball load frequency varies from 0Hz to 1.5Hz.
- Four tracks of wear were formed, and the testing results were measured by the wear mass loss using an electronic scale having 0.01mg accuracy.
- Specific wear rate (Ms) determined by: $Ms = \frac{Mw - Mc}{nl}$

  Where Mw is mass loss of worn disc, Mc is mass loss of dipped disc, and n is number of tests.

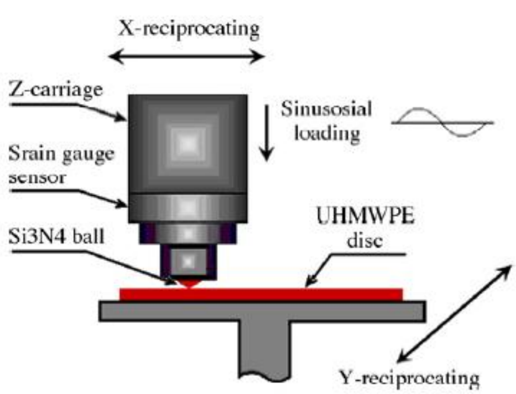


Figure 1-Si_3N_4 Ball and UHMW-PE Disk Contact Schematic [1]

A different study conducted in China University was related to friction and wear behavior of nitrogen ion implantation on UHMW-PE [3]. A UHMW-PE disc was put in contact against a ZrO_2 ceramic ball. The disc rotated and the ceramic ball was fixed on the load arm. The electrical motor was controlled by frequency converter. The tribometer tester measured the tribological behaviors of ion implanted UHMW-PE against ZrO_2 ceramic. The results showed that nitrogen ion implantation improved the hardness of the surface of the material, and increased friction coefficient values.

Test parameters and material selection for N+ implantation were:

- UHMW-PE disc of 5mm thickness and 45mm diameter.
- Surface polished to 0.3 µm.
- ZrO_2 ceramic ball of 3mm diameter.
- Contact load 5N.
- Sliding speed was 0.19 m/s.
- Human plasma as lubricant.
- Test time: 110 minutes for dry friction, and 200 minutes for plasma.
- Room temperature RH 55%.
- UHMW-PE implantation: accelerated energy of 450KeV. Three different N+ doses.

The experiment resulted in a change in color of the original white UHMW-PE. For 5 x 1014 cm^2 density the color changed to orange. For 2.5 x 1015 cm^2 ion density the color changed to bright black.

A study conducted at The Regional Research Laboratory in India was related to sliding wear of PP/UHMW-PE composition blend [2]. UHMW-PE was melted and blended with PP in

different proportions. A pin-on-disc tester apparatus was used where the pin was made of polymer sample and the disc was made of EN-24 steel. The test was done at different pressures and sliding speeds.

Parameter and material were:

- Cylindrical pin size 8 mm diameter and 53mm length.
- Disc is made of EN-24 steel with hardness of 305Hv.
- 1.06-6.34 M Pascal pressure.
- Sliding speed of 0.28-1.09 m/s.
- 300m sliding distance.

The results showed that the wear volume increases uniformly with applied pressure and sliding distance.

The parameters used for those studies will serve a guide in selecting parameters that will be needed to compare the current material to the purchased material. A ball-on-disk Tribometer wear tester at FIU Plasma Lab was used.

1.3.2 Plastic Cutting Machines

Because plastics are thermoplastic processed organic materials with high molecular weight, cutting them requires specialized cutting equipment. In general a plastic cutting machine must possess the following features:

- High level of precision
- Good edge quality
- Energy efficient
- Low maintenance requirements
- Facility of cutting virtually any shape

However since the design of the Paddle Maker machine is intended for a very specialized function, only a few tasks are of key importance to the design and development of our paddle maker. Among these tasks are:

- Ability to move a sheet of the chosen material to the section where holes are to be made.
- Six 7/16" equally spaced holes are to be drilled.
- The machine must be energy efficient.
- It must have low maintenance requirements and be autonomous.

The current manufacturer of these paddles uses a water jet cutter to produce them. A water jet cutter is a device that enables cutting materials like metals and plastics by means of a high speed and pressure water jet, or a mix of water and an abrasive substance. The process is very similar to that of water erosion, yet significantly accelerated and concentrated. It is usually implemented in manufacturing and industrial plants, especially when the material that needs to be cut is sensitive to high temperatures. It is suitable for various kinds of materials such as heat sensitive, delicate and hard ones. Water jet cutting is used for operations such as cutting, shaping, carving, and reaming. Rubber, foam, plastics, composites, stone, tile, metals, food, paper are just some of the materials commonly sliced by water jetting, while tempered glass, diamonds and certain ceramics cannot be cut with it. The versatility, precise cutting and clean finish of abrasive water jet machining, displayed in Appendix E Figure 52, avoids the need for expensive secondary finishing. However, our team believes that due to the material being soft and precision not a big factor, appropriate cutting could be done using conventional cutting tools such as a circular saw. This tool can easily be found in any of the major hardware stores such as Home Depot, Ace Hardware or Grainger.

After doing an extensive search and literature review a company that manufactures machinery with similar processes and principles as those of the Paddle Maker was found. Its name is, Kaltenbach [30] - a 4th generation family owned company and a world leader in metal sawing technology. The company uses CNC for steel beam drilling and metal fabricating (Figure 4). The CNC features contain vertical and horizontal drilling units with a combined saw (Figure 2). A spindle has three axes for drilling with an option to change the tool automatically on each axis. A computer control interface allows the integration of the sawing operation. In addition, the company has a CNC robotic machine designed for coping beams and square tubes. One of its features is material fed pusher conveyor (Figure 3)

Figure 2-Kaltenbach's Drill, Cutting, Roller Table [30]

Figure 3-Hinged Roller Conveyor [30]

Figure 4-**Drilling Assembly [30]**

A local business, Grainman Machinery Corporation, was visited to check for systems that could relate to our proposed machine design. The Company supplies equipment for the grain industry and has several old and new machines, some of which are very similar to the design of the here presented machine. Some pictures of conveyors with end processes like bag sawing, and bag sealing are shown in Appendix T.

2. Project Formulation

2.1 Project Objective

As mentioned earlier, this project will be based on two central objectives. First, the development of a fairly simple machine, capable of making these paddles from a sheet of raw material while maintaining a lower cost per paddle. Secondly, as time allows, our team desires to optimize the current material being used and find a more efficient, cost effective one.

The current paddle material provided by the Gund Company has a tensile strength of 2,500 PSI. However, in an effort to obtain a better wear resistance UHMW-PE, it was found that the current vendor can provide the same material having the same specific gravity, with a higher tensile strength of 5,500 PSI. One of the objectives was to apply a gamma radiation process to an UHMW-PE sheet as time allows. Since cross-linking has been shown to improve the wear

resistance of ultra-high molecular weight polyethylene [2], we investigated the wear loss of radiation cross-linked material.

The development of the machine presented in the conceptual design of this project was the central goal of this project while at the same time research for a better material was conducted as mentioned above. In the process of developing this machine, several sub objectives arose and as they were executed they enhanced the central topic of this project. A few existing technologies used in the manufacturing of plastics were explored to learn crucial information about this topic. Improving the cost of the end product by exploring different vendors and material properties was one of the major objectives underlying our main tasks.

Concentrating on building a functional mechanism that will perform the above mentioned tasks while keeping the complete process at a cost efficient price and safe environmental conditions, was the focus of this project.

2.2 Design Specifications

In this section all the specifications gathered while designing the system are presented. Specifications are separated into different categories for better understanding.

2.2.1 Motor Selection

Throughout this project, when selecting motors, many questions arose. What kind of motor should be used; DC, AC, or stepper motors? What Torque and Power are these motors going to need to accomplish their respective tasks? What RPM will they need to run at? To answer all of these questions an extensive literature survey was conducted so that the team could have an understanding of similar machinery already on the market. Further detailed explanation on motor selection is included in Section 6 of this report and in Appendix J: Torque Calculations.

2.2.2 Drilling Control

The paddle design currently being used in the RBT conveyors features seven 7/16" holes spaced at 5", however Nestor has noticed that while replacing old paddles with new ones, that the middle hole is located where the paddles break most of the time. Therefore we are going to avoid making this middle hole in order to make the paddle's design more lasting and stable. This will also reduce drilling time and therefore the cost of producing one paddle. Based on this specification the drill bit was selected and the G-code program written to instruct the Mach 3 how to move the stepper motors.

The fabrication of the finished product was influenced heavily by the way the three different processes operate simultaneously; namely, first the roller table, then the drilling operation, then the cutting, finally the roller table moves the thickness of the paddles and the whole cycle starts over.

2.2.3 Movement Control

The Paddle Maker machine has three main moving parts: the roller table, the drilling station and the saw station. Specifications for the roller table were to move a sheet of UHMW-PE of 37¼" by 38" by ½" weighing about 40 lbs. Based on these sizes the rollers were bought and the table frame built. Also a Torque analysis was done to find the required torque needed to move the sheet forward by a stepper motor. Details are found on Section 6 and in Appendix J, named "Torques Calculation". To move the drilling assembly up and down a linear stage was acquired. Selection criteria for this element were a travel distance of at least 2 inches and to be able to carry at least nine pounds which is what our drilling assembly weighs. Also a torque calculation was done to be able to select an appropriate stepper motor. To move the drilling assembly in the x-axis, a much smaller torque would be required since the weight of the

assembly would be supported by two high precision shafts and the whole thread rod that moves the piece. The same applies to the stepper motor that moves the circular saw assembly horizontally. Thus a kit of four stepper motors was purchased to meet the highest torque requirement given by the vertical linear stage. By buying them together we guaranteed the functioning of the system would be appropriate and the cost of the machine is reduced.

2.3 Constraints and Limitations

Constraints and limitations were explained in detail in the previous subsections, where the specifications for every component of the machine were discussed. Some of the limitations not discussed previously were that the drilling station would take about 2 minutes to perform the drilling of the six holes, which is mainly due to the chosen setup of the assembly and the speed of the stepper motors. Also the table was built to fit one specific size of sheet (37¼” by 38”), thus the machine is limited to this size of raw material, bigger sheets would have to be cut to size before being input into the Paddle Maker. Future work will solve this issue by having an adjustable table workstation.

2.3.1 Paddle Material

The current paddle material is UHMW-PE. This material is good for friction resistance and has proven to perform adequately when used in Flight a Drag Conveyors. Thus our team tried to find a material similar or better to the one being currently used and that is economically feasible. It was found that UHMW-PE can be in fact improved when exposed to different procedures explained in detail in the materials section of this report.

3. Design Alternatives

3.1 Overview of Conceptual Designs Developed

The process of developing and selecting several conceptual designs for the desired machine that would produce the needed paddles was a crucial step in the advancement of this project. During the first stage of brainstorming, many ideas defining the requirements were considered while keeping in mind the end product requirements. After recording ideas for several days the first informal drawings were discussed and several changes were recommended as everyone in the team agreed.

Because the machine is composed of three subsystems, namely: drilling, roller table and cutting, the conceptual design section is also divided into three sections that expose different approaches to designing the Paddle Maker.

3.2 Cutting

3.2.1 Design Alternative 1- Water Jet Robotic Platform

The first design discussed was a robotic platform equipped with a water jet specially designed to cut through the materials selected in the Material Selection part of this report. Water jet systems typically have very unique capabilities that make them more advantageous and effective over traditional machining. Their ability to cut while keeping low temperatures makes them practically attractive to industries handling flammable materials, such as natural gas and petroleum. In addition, material cut by water jet has a smooth satin-like finish. Although highly efficient and popular in industrial applications, where versatility is an essential factor, these modern systems have complex controls and functionality and are relatively expensive. Since our

application does not require high accuracy, and because of the high cost of this alternative, it will not be considered for our design.

3.2.2 Design Alternative 2 -Laser Cutter

Another typical system widely used in modern manufacturing to cut almost any type of material and discussed while brainstorming was laser cutters. Basically, laser cutting consists of a high power laser guided by a computer to burn a groove in the material near the emitting component. The material being removed can be melted by the high temperatures and or blown away by high velocity fluids, usually gases. Laser cutters present several advantages over the majority of the traditional cutter systems, consequently making them especially popular as an innovative emerging technology. They produce extremely smooth surfaces as well as very precise cuts and usually cut fairly fast if the material thickness is not extreme. The single most attractive characteristic of a laser cutter is the lack of physical contact between the tool and the piece being worked on, completely eliminating the wear and tear factor present in traditional processes. Furthermore laser cutting requires considerably high electric power thus increasing the operation cost of the machinery. Because the main objective of this machine is to reduce the paddle cost, it is not feasible to include this technology into the machine given that high precision is not required.

3.2.3 Design Alternative 3 –Circular Saw Workstation

The cutting along the width will be done by a circular saw blade specially designed to cut plastic (Figure 5). This particular blade has unique features like the sharpening of the tooth that allows for a cleaner and faster cut, which makes it highly efficient when cutting plastic. The width of the cut done by the blade is also a parameter that will be studied carefully, since a wider

cut means more wasted material. The cutting blade will travel along the complete width of the plastic sheet, powered by an electric motor that will rotate in both directions moving the blade back and forth.

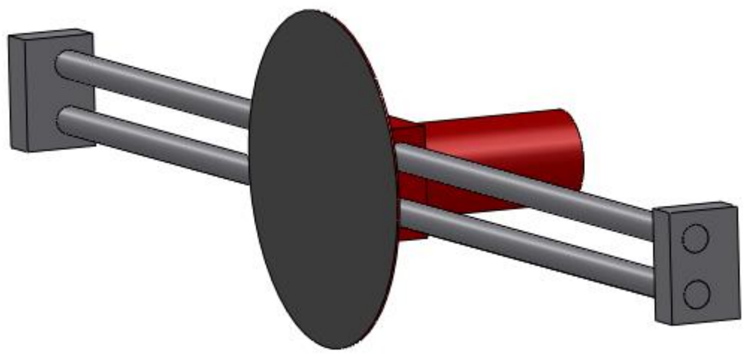


Figure 5-Circular Saw Workstation Design Alternative

The angle in the scraping corner of the paddle was going to be cut by a corner round router (Figure 6) powered by a motor turning it and is to be installed in an assembly together with the saw, which in turn will be moved by a stepper motor. The installation of the router and the powering motor are not done in the current prototype but will be integrated in the machine in the near future.

Figure 6-Round Corner Router

Feed rate for all components were analyzed theoretically and then tested physically, particularly those of the cutting tools, to assure that the material did not burn in the process damaging the tools or the machine.

3.3 Drilling

3.3.1 Design Alternative 1 – Mechanical Drilling Assembly

Another approach for our machine was to build a straightforward combination of mechanical components, equipped with electrical controls. This design is depicted in Figure 7. As raw material will be obtained in the form of sheets cut to the required width the cutting performed by the machine will be along the width of the sheet. In this design the holes were going to be drilled by a set of six drill bits mounted in a supporting base and pre-set to the desired measurements. By having all the drill bits mounted on fixed positions, the accuracy of the distances between holes, which is the only critical dimension in the complete part, is assured. This will also improve drilling time since all holes will be drilled simultaneously. The drill bits used will be specifically designed for drilling hard and soft plastics and they also feature characteristics, such as point and rake angles, which minimize or eliminate left-overs from the material being removed while cutting the holes, resulting in a smoother internal surface. More details about this drill bit can be found at Appendix F of this report. Some of the concerns with this design are the force required to press all drills at once against the material being drilled and the vibration created by all the drill bits acting on the material simultaneously.

The six drill bits should be interconnected by a mechanical system and driven by an electric motor mounted in the center of the frame supporting the drill bits and connected to the center chuck. The up and down movement will be provided by a stepper motor. The two systems

considered were a belt system or a chain and sprocket combination. Both of these systems are of considerably higher cost and complexity. Hence their construction and assembly would take longer than that of the final design presented in the next section.

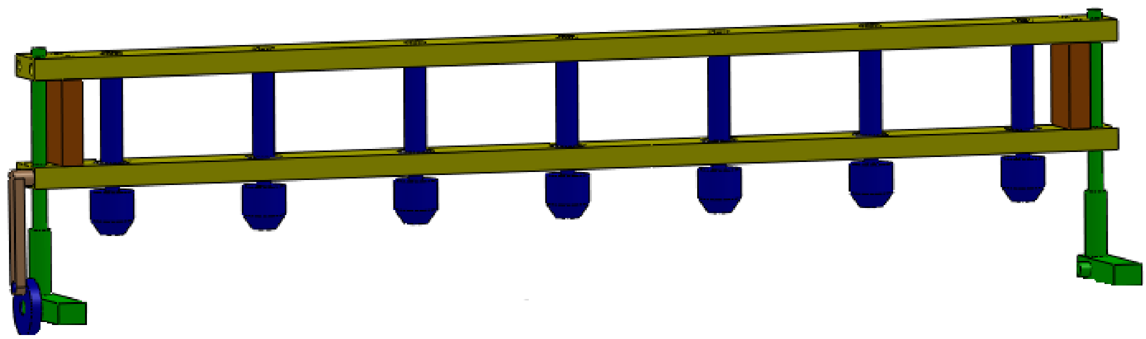


Figure 7-Mechanical Drilling Assembly Design

3.3.2 Design Alternative 2 – Drilling WorkStation

The last major design explored was a “CNC–like” system, also referred to in this report as a drilling station (Figure 8). The concept of CNC goes back to the 40’s and 50’s when the combination of existing machines with electrical controls started to become popular. The rapid development of electronics in the last few decades has affected the CNC technology accordingly. This has revolutionized the manufacturing industries making almost every process faster, more accurate, and consistent. A great deal of knowledge has been gathered by industries through all these developments and a considerably large number of applications are in use today, making the components of CNC available in almost every possible form. The concept discussed for this project was based on the combination of a cutter and a drill, mounted on two linear motion systems, moved by stepper motors and controlled by a driver connected to a computer. Some of the concerns when discussing this design were the price of accurately controlling the position of

the drill when moving from one position to the next, and the constant movement of the electrical wires connected to all the moving devices.

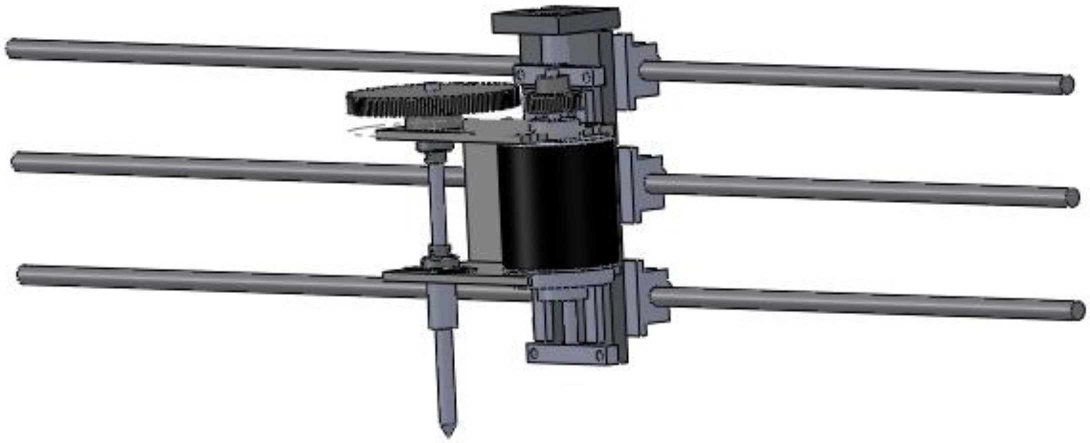


Figure 8-Drilling Workstation Design

3.4 Material Movement

3.4.1 Design Alternative 1 – Roller Table

Since early in the conception of this project it was realized that some sort of mechanism to move the UHMW-PE sheet from point A to B while controlling the rate of movement as required. One approach to solving this issue was to build a roller table as seen in the picture below. This design includes nine galvanized steel rollers, purposely separated at different distances to minimize the torque required to move the work piece forward. A stepper motor was selected that would easily overcome this torque, and both the legs and frame were made of standard 1” x 2” steel tubing.

Figure 9-Roller Table Design Alternative

3.4.2 Design Alternative 2 – Automatic Material Handling Table

The table illustrated below was one of the alternatives discussed while brainstorming on how to move the sheet of material to the specified position where the other processes were going to be conducted. The way this works is having two sliders, one long the x-axis, through which a pusher slides, and another on the side that holds the sheet of polyethylene and moves with it at the same rate the pusher displaces the sheet forward. Both of these mechanisms are moved by stepper motors turning two lead screws. They lay in an aluminum table to provide system stability and accuracy. One of the biggest disadvantages of this design is that it requires a lot of machining to bring this model to life and in the process a lot of material would be needed, thus the price of developing this model would be high.

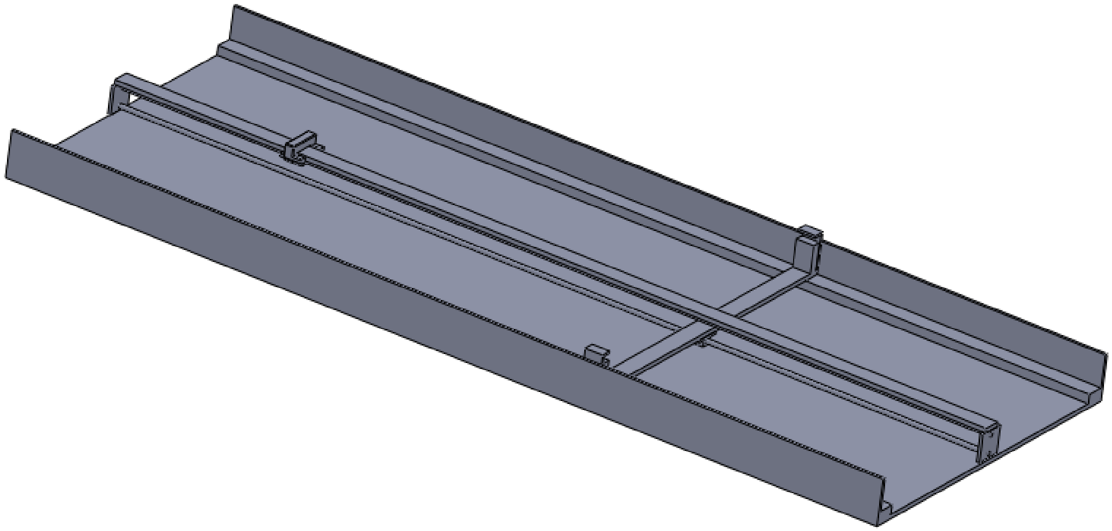


Figure 10-Automatic Table Design Alternative Trimetric View

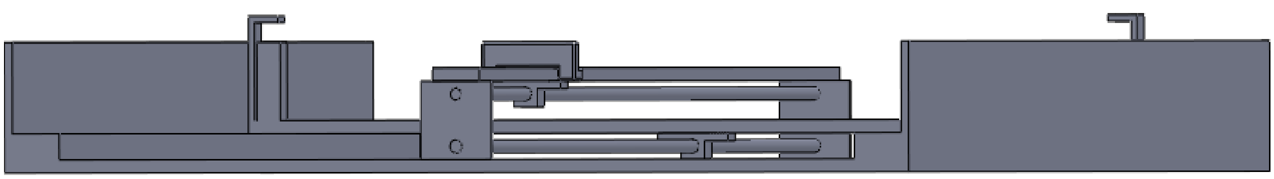


Figure 11-Automatic Table Design Alternative Inclined View

3.5 Feasibility Assessment

Research of all these possible options, while keeping in mind cost, availability, complexity and material being handled among other factors led us to choose the design presented below. As can be seen the roller table was chosen for moving the work material and the CNC –like approach using, lead screws and stepper motors, was used for both the drill and sawing

station. This design was the most time effective and cost efficient approach for doing a Paddle Maker machine.

Figure 12-Overall Design

Some small details are not included in this drawing. A section view of the first draft is shown below.

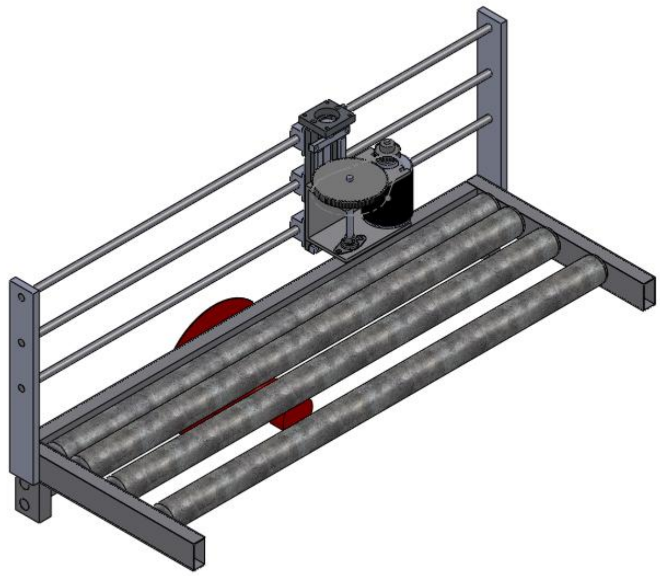


Figure 13-Section View of Proposal Design

Next an exploded view (Figure 14) is presented to help identify the different components that make up the whole assembly.

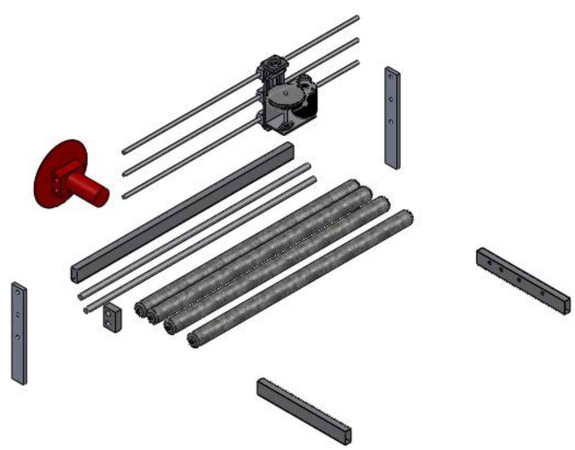


Figure 14-Exploded View of Proposal Design

A drawing of the finished paddle (Figure 15) was done to help visualize the needed proccesses.

Figure 15-Targeted Finished Paddle

3.6 Design Process Diagram

3.6.1 Material Selection Logic Diagram

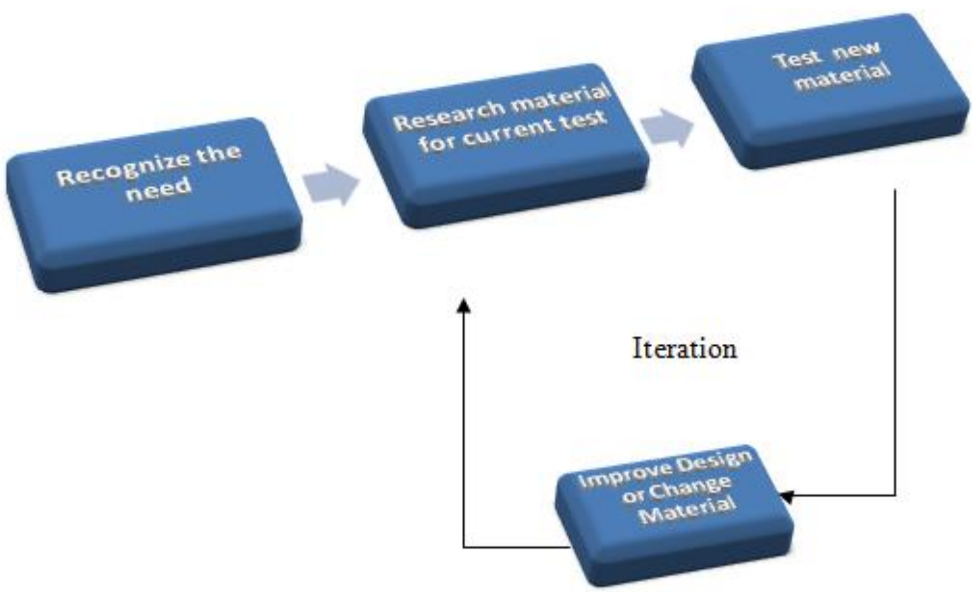


Figure 16-Steps for Material Optimization Process

The optimization process involved the four steps mapped above and detailed as follows.

Step 1: Recognized the need- the improvement of the product (obtaining a better friction resistant material) is the most important part of the entire process.

Step 2: Research material for new current test- this part of the process included finding a product with similar or improved properties to that of polyethylene.

Step 3: Test the new material- after receiving the material it was tested and compared to polyethylene wear.

Step 4: Improve the design- As a result of the test performed on the new material, quantitative measure were obtained and results are presented in following sections.

3.6.2 Proposed Machine Design Logic Diagram

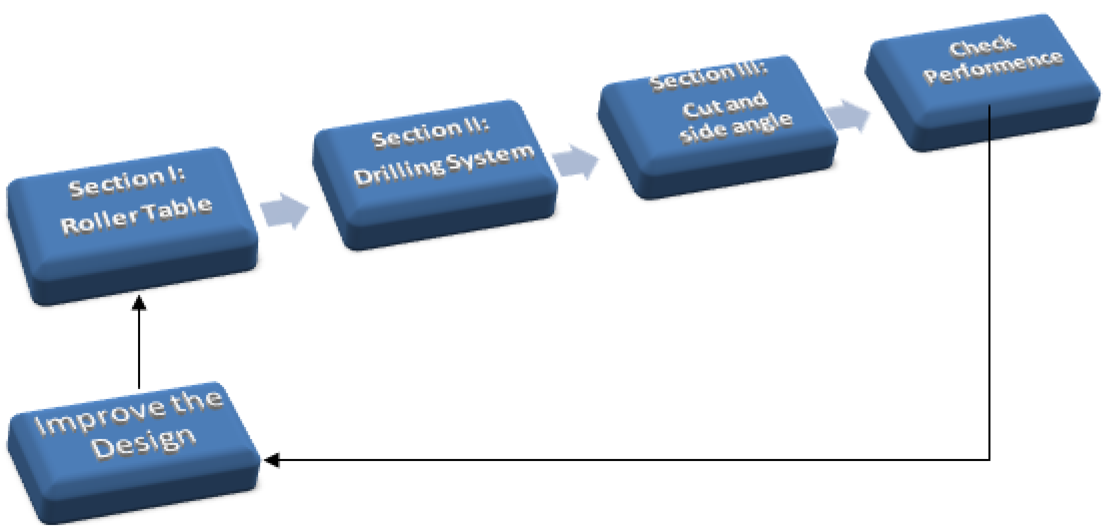


Figure 17-Machine Design Process

Step 1: The machine was designed such that the plastic sheet will be easily rolled over a platform (roller table) to the drilling area.

Step 2: A table workstation consisting of two linear stages and a drill system, moved by stepper motors, were designed to create holes on the plastic sheets.

Step 3: A saw moving by means of a linear stage and stepper motor cuts the paddle to required dimensions. Also a round corner router, not included in the prototype, moving by the same system as the saw could do the side angle.

Step 4: Evaluation of the process was performed on the accuracy of the design.

Step 5: Improvements were done until the final product was obtained successfully.

3.7 Proposed Machine Design

After considering all of the above mentioned systems and procedures, the final conclusions were:

- The design preference for drilling was Design Alternative 2 - Drilling WorkStation.
- The design preference for material movement was Design Alternative 1 - Roller Table.
- The design preference for cutting was Design Alternative 3 – Circular Saw Workstation

The complete design included a table with rollers that facilitated the movement of the sheet toward the drilling station. This table consists of several, free motion rollers, and one driver roller that pulls the raw sheet forward by a prescribed distance, which is the desired width of the paddle. Then the drilling system moves through linear stages in the horizontal and vertical directions to make the six holes needed.

4. Project Management

4.1 Timeline

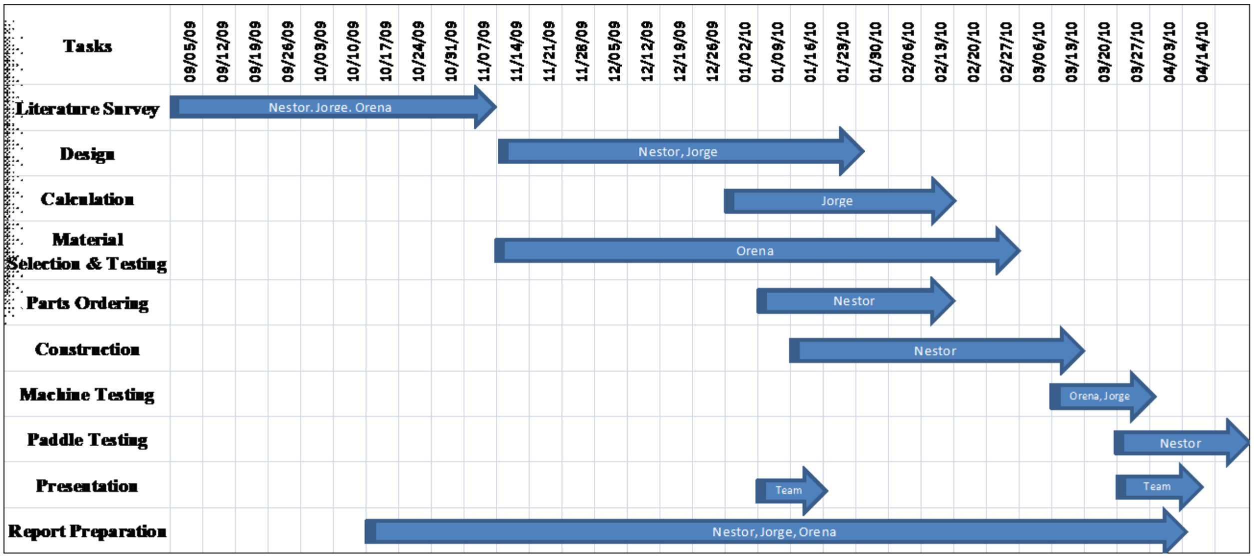


Figure 18-Project Timeline

4.2 Team Breakdown of Responsibilities, Tasks and Roles

The timeline and responsibilities table is an approximation of the time spent in the different tasks and it only reflects the most important subjects. The team members names appearing in the arrows just represent the person in charge of that specific category. The team members' tasks reflected below just show the team member's main responsibilities; however every member participated in every specific area and in the report as a whole.

The table below shows the approximated number of hours each member spent for each category.

Table 1-Numbers of Hours Spent

Category	Nestor	Jorge	Orena
Literature Survey	85	83	90
Machine Design	61	58	46
Machine Drawing	55	55	12
Calculations	9	26	19
Material Search	3	2	19
Material Test	5	4	51
Machine Components Ordering	10	8	4
Construction	55	48	39
Machine Testing	48	46	40
Software Installation	3	3	3
Software Verification	4	4	3
Paddle Testing	2	1	1
Presentation	6	7	9
Report Structure and Contents	50	48	53
Total Hours	396	393	389

4.3 Patent/Copyright Application

For an invention to be patented such idea needs to be novel and the inventor must show how the invention works. In addition, it is important to keep records of all details; including drawings, brainstorming and dates of importance. To ensure it is a new idea one must search the US (sometimes foreign) patents, and technical journals for related inventions. One tool usually used by lawyers when they want to research whether an invention is original or not is google.com/patents.

A US patent cost depends on the technology involved.

- The initial cost to have a patent searched, and to have an opinion if the idea is patentable is $650 to $1000.
- A patent application which includes 2-3 drawings costs $150 per one drawing for a total of $450.
- Next, an abstract and detailed description has to be prepared for the application. The fees in simple mechanical cases are $4500. The fees for software, computers, and electrical systems are $7000. For a more complex system such as shock absorbing prostatic device the cost is $15,000. For highly complex such as telecommunication networking system the fee would be $15,000 +.
- Next, the application filing fee costing $355
- An amendment for the application can cost up to $2000 in attorney fees.
- Final patent issue to the USPTO costs is up to $1300
- Maintenance fees range $2995-$5790, and it increases over the life of the patent.

The patent process is relatively expensive. An inventor can spend up to $10,000 in order to obtain a US patent. An additional fee of $20,000 for a patent protection in a foreign country can be expected. Moreover it takes about 36 months for the complete process.

A search for an automated plastic cutting, drilling, and saw machine, using US patents web sites[28], led to no results for these specific combined functions. The new paddle maker machine is a unique design for a very particular application that will indeed save time and money to any company using Drag-a-Flight Conveyor.

Even though the design has a low cost and provides a unique application, the team has no intention of filing for a patent at this point since this project was supported and thus intended for the Miami facility of Vulcan Material. Furthermore the possible clients soliciting for this

machine is limited, which makes profiting from it a risky venture. In addition, the Paddle Maker is composed of many different mechanisms that have long been patented, namely: drills, circular saws, roller table and CNC workstations, which could also make obtaining a patent even harder.

4.4 Commercialization of the Final Product

In order for The Paddle Maker to be commercially ready many different parts need to be optimized, for instance, the drilling assembly motor and the two lead screws of the saw and drilling assembly respectively.

The prototype presented in this report, was built just to demonstrate that our design works, thus some parts were substituted to be able to meet our budget. In order to transform this prototype into a commercially viable product, the drilling motor needs to be substituted with the one suggested in Appendix L, also the whole thread rods need to be substituted with lead screws shown in Appendix P, so that both the saw and drill assembly run smoothly and more accurately. Also a slider table as proposed in the future work section should be included to the machine as an accessory to be able to collect the paddles.

4.5 Discussion

Management is one of the most important tasks of any engineering project. Weekly meetings were held to discuss tasks to be accomplished, and to ensure that the Table of Responsibilities was being followed in a timely manner. Different tasks were split between members according to their abilities, yet the more intensive tasks like design, construction, optimization and testing were mostly accomplished by group work. Cost was an important factor affecting nearly every decision throughout the realization of this project. To meet the budget and time deadlines some concessions had to be made as mentioned in section 4.4 and Future Work in

section 10, yet because of having had a well timed and organized breakdown of tasks, our prototype was successful and both the machine and the paddles met expectations.

5. Engineering Design and Analysis

5.1 Structural Design

Structural design and analysis in the engineering process of creating functional machinery are extremely important steps that need to be revised thoroughly. Sometimes restricted by the objective conditions and specifications of the output product, the challenge presented in designing structures goes beyond the scope of this project. Based on practical knowledge, information gathered from numerous sources and the help of computational software, such as SolidWorks, Beam 2D 3.1 and Excel, a logical design and analysis of the here presented structure and mechanism was conducted. Some preliminary analyses were done and are presented in the following section of this paper.

Selecting major components for the machine being designed was a fundamental step in the task of designing and engineering a working device that could operate under the presented restrictions and conditions. Some of the factors considered for component selection were the cutting speed and the feed speed of the drill bit.

For the construction of the frame, standard rectangular 2”×1” tubing was used in combination with several other small structural steel parts. Several pieces were made of aluminum to reduce weight, cost and to increase durability of the completed mechanism.

The selection of the main electrical components for this machine was a challenge that was directly discussed with the team advisor, other professors and several of our electrical engineering colleagues before buying the motors and controller kit.

Fundamentals of mechanics of materials and material properties were applied in the search for a material that would have better performance when operating under the specified conditions.

5.2 Dimensions

Some the dimensions of interest in this project have already been mentioned in previous sections. Production time of a paddle, machine cost including maintenance, and raw material cost are some of the most significant fundamental aspects of the project.

The final cost of the completed machine was intended to be kept under $2000 USD for future commercialization purposes. Quotes from several different companies and materials were obtained and are presented in the following section with the intension of reducing material cost.

5.3 Material Selection

5.3.1 Paddle Material

E-Beam Services Inc. provides cross-linking and chain session services for a price of $900 to any sheet size. The cross-linked cost per sheet shown in the table from Horn Plastic Inc. is not expensive because this was an exchange with other vendor’s material. The cross-linked UHMW-PE could not be welded and therefore was traded off with regular UHMW-PE sheet. We were not able to get information on the data sheet. However the sample color is Orange which indicates that the UHMW-PE had undergone through a process.

Material Cost for UHMW-PE Sheet

Table 2-UHMW Cost

Vender Name	Size TxWxL	Cost per Sheet ($)	Cut to length Cost (CTL 37-1/4”)
Interstate Plastic.com	½” x 48” x 72”	471	500
RPlastic.com	½” x 48” x 120”	356	395
The Gund Company Inc.	¼” x 38” x 48”	216	250
Horn Plastic Inc. (With Crosslink Process)	¼” x 60” x 96”	*242	285

5.3.2 Machine Major Components

The proposed system is composed of several mechanical and electrical components that work simultaneously to achieve the targeted end product. The major components are as follow:

- Beginning with a DC electric motor that provides rotational motion to the drill assembly.
- A DC motor that provides rotational motion for the saw assembly.
- A belt and timing gear system that transfers the rotating motion and torque from the motor to the drill bit assembled in a custom made shaft.
- The drill bit shaft has a simple chuck machined on it, so that the drill bit can be removed if necessary. This shaft was machined to custom fit the existing assembly to reduce vibrations created by centricity differences.
- A drill bit specially design for drilling hard and soft plastics.
- High speed bearings that support the shafts holding the chucks.

- Four stepper motors that provide linear motion to the drilling workstation in the vertically and horizontally direction and to the cutter in the horizontal direction parallel to that of the drilling, and rotational motion to the roller table.
- A 6½" circular saw powered by an electric motor, to make the horizontal cut to the desired width.
- A table composed of several rollers where the sheet of raw material slides towards the cutting machine.

As mentioned above, these are some of the most essential components included in the assembly of the present machine; as improvements are made more components will be required.

5.4 Force Analysis

The force analysis is mostly covered in Appendix J: Torque Calculations section. Here the torque needed for the two main stages of the machine was analyzed, namely: the linear stage and the roller table. The torque for the roller table stepper motor was found to be approximately 0.23 Newton per meter (Nm) or 32.7 ounces per inch (OPI); while the torque that the stepper motor on the linear stage would need to exert was found to be around 17.7 ounces per inch (OPI) for the worst case scenario - which is when the drilling assembly is going up; this torque is called raising Torque or $T_{R.}$ All assumed values specified in Appendix J were those of worst case scenarios taken from mentioned sources.

In the case of the circular saw motor, the drilling motor and the stepper motors providing the horizontal movement for the drilling assembly, finding the necessary torque was accomplished as follows.

First we looked at different similar saws in the market and found that the best one to compare to was a cordless one - since we are going to use a DC motor to power the saw. Usually cordless saws range around 1/20 horse power (HP) and have a torque of about 7.5 (OPI). Then Mr. Zicarelli from the Engineering Manufacturing Center at Florida International University recommended using Machinist Toolbox, which is known computer software, to find an estimate of what power would take to cut UHMW-PE. Using this program it was found the horsepower and torque would be 1/10 HP and 15 (OPI) respectively. Then tests were done using a DeWALT cordless saw. Several pieces of the material to be used were cut successfully and then from the specs of the machine, the power was found to be 1/20 HP. Thus after doing this set of tests a range of power and torque required to cut this material was estimated. For simplicity, it was decided to use an existing cordless saw and just replace the blade with one for plastics, guaranteeing success for the given case.

For the drilling motor similar steps as those for the circular saw motor were undertaken. From the literature survey it was found that similar cordless power drills usually range from 1/20 to 1/5 HP and 50 to 200 OPI for the torques, while from the Machinist Toolbox the estimation was ¼ HP and 214 OPI. To find the correct RPM to operate the drill bit a drill press was used. Several holes were drilled letting the speed of the driller vary. It was found that anywhere in the range of 700 to 1300 RPM the sheet could be drilled and good finished holes would be obtained. Then tests to find torque and horsepower were done by using a Dewaltt cordless drill whose specifications were 1/10 Hp and 100 OPI. Combining this information, it was decided that a motor capable of providing 1/8 HP and 170 OPI was acceptable. Yet this motor speed was much greater than needed, so as part of the assembly a gear pulley system was included to reduce the

speed of the assembly to approximately 1300 RPM, which is the fastest speed achieved in our testing, while still obtaining quality holes.

Since the stepper motors torque requirements for the roller table and the linear stage were the ones expected to be higher than those used in the horizontal movement of the saw assembly and the drilling assembly, a kit was purchased to exceed the specifications of the higher torque component, in this case the linear stage (17.7 OPI). The drill assembly and saw assembly require less torque due to their providing displacement in the x direction and not carrying as much load and having two high precision rods and bearings supporting them. The kit bought was a great decision since it saves us time and money. A single package provided us with everything needed for controlling the displacements of the machine: a driver, four (270 OPI) stepper motors, one power source and a controlling board. Another major reason why these steppers were chosen is because their compatibility with the mounting of the linear stage.

5.5 Dynamic/Vibration Analysis

The team consulted Dr. Levy on how to conduct vibration analysis on the system. Dr. Levy recommended a simple method of analysis in order to find an approximation of the first natural frequency that could be compared to the frequency that the motors are running at. He suggested that if the natural frequency of the system is different than the natural frequency of all motors then no resonance will occur and the design would be safe of critical vibrations. If the system frequency falls within ± 10% of the natural frequency of any motor, it is not considered safe and a simple vibration absorber composed of springs and mass should be used.

The paddle maker machine is formed by several subsystems: namely the drilling station, sawing assembly and a roller table. For that reason it was chosen to use Dunkerley's formula [31] to determine the system's final natural frequency. Dunkerley's formula gives approximate

values of the fundamental frequency of a composite system in terms of the natural frequencies of its components. The fundamental frequency showing in Figure 19 was used to include all subsystems.

$$\frac{1}{\omega_n^2} \simeq \frac{1}{\omega_1^2} + \frac{1}{\omega_2^2} + \frac{1}{\omega_3^2} = \frac{1}{\omega_{\text{table}}^2} + \frac{1}{\omega_{\text{drill}}^2} + \frac{1}{\omega_{\text{saw}}^2} = \frac{1}{\omega_{\text{system}}^2}$$

Figure 19-Dunkerley' Formula Used for the System

The natural frequency formula is $\boldsymbol{\omega = \sqrt{k/m}}$ where **k** is the spring coefficient and **m** is the mass.

- **k** $_{\textbf{equivalent}}$ and total **Mass** for each subsystem was calculated:
  - **Roller Conveyor assembly-** The legs experience the same deflection; thus the k equivalent is in parallel. They were simulated as fixed beams of circular cross-section. The nine rollers were modeled as rods experiencing the same deflection, hence they were considered in parallel. The frame of the roller table was divided into frame $_L$ and frame $_{W,}$ and both were modeled as fixed beams with a thin walled thickness cross-section. The legs, frame and rollers can be taken as in series since they all experience the same load.
  - **Drilling assembly-** The two support rods are considered fixed, and the lead screw is considered as a free rod. The drill station which includes: electrical motor, stepper motor, rods, and linear bearings are considered as one mass. The two rods and lead screw carry the same load, namely the weight of the assembly, thus they are considered to be in series.

- **Sawing assembly-** Includes the same parts as the drilling assembly. The only difference is the length of the rods and lead screw. The saw blade and motor are considered as one mass. The rods and lead screw carry the same load, namely the weight of the assembly, thus they are considered to be in series.
- **Sheet mover assembly-** the stepper motor and wheels move the sheet to be cut to length very slowly. The wheels only turn approximately 3/4 of a revolution to move the sheet the prescribed distance and thus this assembly including its respective motor is deemed stationary and is excluded from the vibration analysis, though its mass is included in the roller's table mass.

- The total natural frequency for the system was calculated to be **1.009 rad/sec.**
- All motors frequency was obtained by converting RPM to Rad/sec. The smallest natural frequency for the drilling stepper motor calculated to be **5.236 rad/sec**
- Since $\boldsymbol{\omega}_{\textbf{system}}$ is different than any $\boldsymbol{\omega}_{\textbf{any motor}}$, and since the value does not fall within $\pm$ 10% of any motor's frequency value, the machine should have no resonance.

5.6 Deflection Analysis

Member deflection is a considerably important topic in the design of any structure. Even though the system here presented consists of a combination of simple structures, determining the deflection of the key parts of the machine was of interest.

The linear shafts holding the drilling assembly, being the thinnest and longer members, were the components where the major deflection was expected. The deflection and other properties of interest for these supporting shafts were calculated using the very well known software Beam 2D version 3.1 and are presented in Appendix K. The two tentative dimensions for these shafts were 3/8" and 1/2". The load carried by two of these shafts at any time is 8 lbs,

but to be on the safe side, a 10 lbs load, located at the center, was simulated on a single shaft. After performing this analysis the ½" shaft was picked based on minimum deflection specification. The maximum deflection was found to be 0.03746543" at the center of the shaft where the load was being applied (Figure 20).

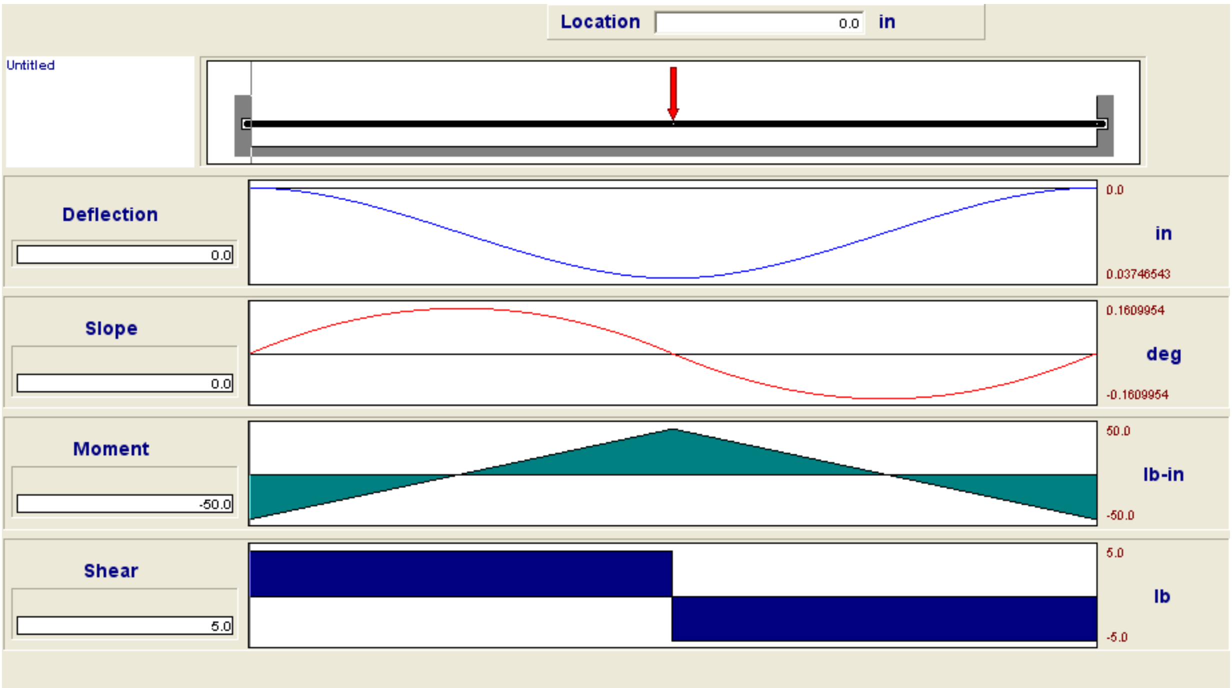


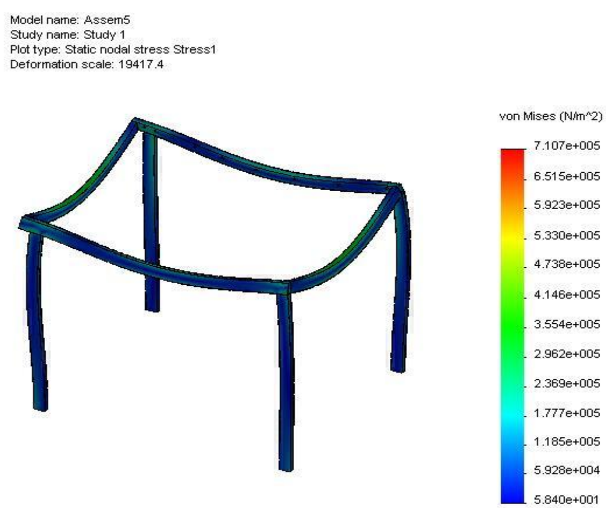
Figure 20-Deflection Analysis of Linear Shaft

5.7 Material Analysis for Machine Assemblies

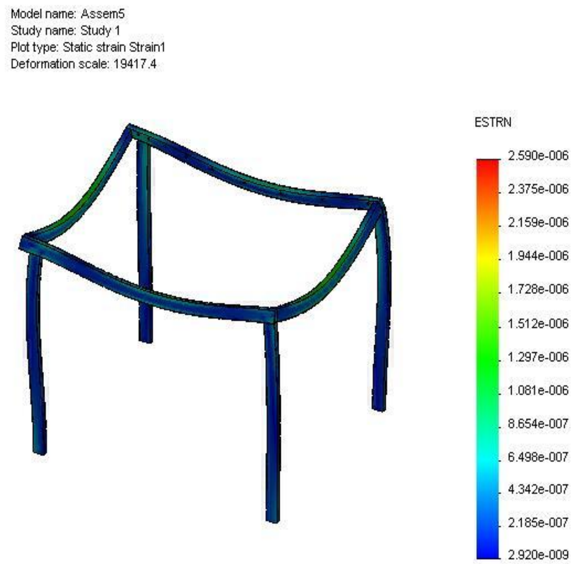
Structural analysis involves the consideration of physical properties in the effort to predict and study the response of a structure to the adversities of the environment in which it is operating. Involving the fundamental of material failure theories, mechanics, as well as non static loading, the fundamental goal of structural study is the estimation of stresses, internal forces and physical deformations. This portion of the engineering design process has become essentially important as a result from the demand to save money in the realization of direct testing.

When building any kind of machinery, it is of great importance to estimate the life span of the design by predicting failure using theoretical analysis. Structural analysis to all possible components was done using SolidWorks Cosmos Works in order to determine their performance under continuous applied loads. Finite element analysis was used to make sure the structure is safe. Obtaining a high factor of safety will guarantee reliability of the Paddle Maker and minimize vibrations. Furthermore Deflection Analysis was applied to determine how much the different parts of the machine displace when under stress and the results are presented in the following.

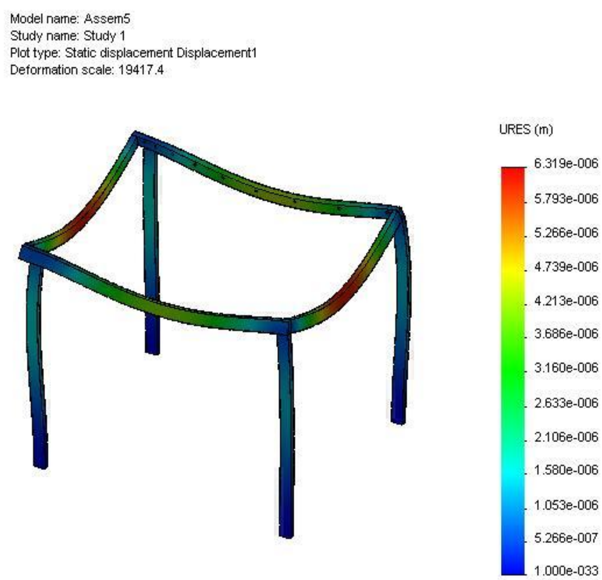
5.7.1 Stress Analysis



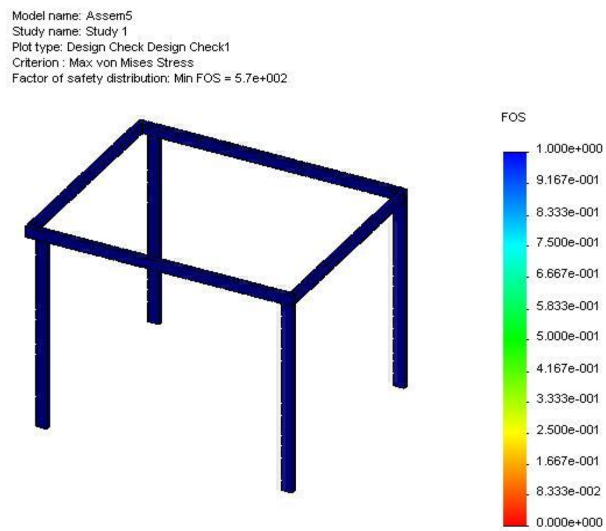
5.7.2 Strain analysis



5.7.3 Displacement



5.7.4 Factor of Safety analysis



Stress and Strain analysis results show a very safe and stable table model .Deflection Analysis shows that the center of the side of the table is the one experiencing the most deflection, yet this value is very small, approximately 6.31 $*10^{-6}$ inch, thus the current design it also a good one on this aspect. The factor of Safety is very big, which is desirable for a machine that is expected to have a long lifespan.

5.8 Cost Analysis for One Paddle

Below you will find a Table that estimates the cost of producing one paddle with the proposed design, the Paddle Maker. As it can be seen the cheapest option will imply a saving of $7.75 per paddle, when compared with what the actual manufacturer (The Gund Company) charges Vulcan Materials, $13 per paddle. Charges which multiplied by the 114 paddles needed for the conveyor belt would represent a saving of almost $884 per paddle shipment. Considering that a new set of paddles must be installed every month, in order to efficiently load with powder

cement the trucks, the total savings for the company would be around $10,606 a year. This is only in the Miami Facility. If every facility that uses Drag-A-Flight conveyors today for load product from trains to trucks can save that much money, the paddle maker could mean huge savings not only for Vulcan Materials but also for any company in the construction field interested in this technology.

Table 3-Paddle Production Cost

Polyethelene Sheet Provider	Size	Cost per sheet	Time(minutes)	Machine Functioning Cost ($ per hour)	Machine Functioning Cost ($)	1-paddle Production Cost ($)
Interstate Plastic.com	1/2" x 37" x72"	$500	205.714	0.256	0.877	12.174
Rplastics.com	1/2" x 37" x120"	$395	342.857	0.426	2.436	5.796
The Gund Company	1/2" x 37" x72"	$215	205.714	0.256	0.877	5.247
Current Price						13

Below a discussion of the equations used to produce this table is presented.

- Time(minutes)= 5 min * (sheet size/paddle size)
- Machine functioning cost = Power * (hours to produce paddles)*($0.10 per KW-h)
- Cost of 1 paddle = (sheet cost+ machine functioning cost) / (amount of paddles produced from that sheet).

In the time equation, five minutes is the time empirically determined required to manufacture a single paddle. That multiplied by the amount of paddles obtained from each sheet gives you the time that it takes to make paddles out of that sheet.

The Paddle Maker uses 2 DC motors and 4 stepper motors that account for the total horsepower of the machinery to be approximately 1 HP. This is converted to KW, and then to KW-h using the time calculated in the first step. That value times the average KW per hour cost in Florida, namely $0.10 yields the machine functioning cost.

In order to obtain the amount of paddles produced from a given sheet, the size of the sheet is divided by the desired paddle size.

6. Prototype Construction

6.1 Description of Prototype

The target of this project was to build a machine that would produce construction paddles to be fitted in a Drag-A-Flight Conveyor .These paddles needs to be 37¼" long, ½" thick and 1¾" wide, having six holes 7/16" in diameter each, spaced by a distance of 5½". The current design of the paddle also features an angle cut in one of the sides to decrease friction.

A machine, The Paddle Maker, was constructed to produce the paddles autonomously from a given sheet of raw material. Thus the machine first moves the sheet of raw material to the position where a pulley-belt system driving the drill bits makes the holes. Then a saw moves by means of a stepper motor and takes care of the cutting.

6.2 Parts List

6.2.1 Motors and Stepping Motors

Four Nema 23 Hybrid Bipolar Stepper Motors of 270 oz-in, 1/4" dual shafts, were used to move the different linear mechanisms. Typically controlled by a computer and driver, these motor are among the most common systems used in machines requiring motion control. Advancements in electronic controls have made steppers motors more popular than ever in almost every modern industry.

The torque of these motors greatly exceeds that required by the system; the reason for this is that these motors were bought in a complete kit, including the power supply and

controller. By having all stepper motors of the same size and frame will facilitate future maintenance.

6.2.2 Gears and Timer Belt

The design of the machine required means transmitting power from the electric motor to the drilling shaft while reducing the speed of the motor by a ratio of 3:1. To accomplish this, a combination of two timing gears was selected since no slippage between the belt and the pulleys was desired.

The driving pulley was chosen to be a 24 tooth, Acetal Plastic, with Aluminum Hub to meet the size of the motor's shaft. The driven pulley was required to be 72-tooth to meet the required rpm for consistent drilling and acceptable hole finishing. This last pulley was not available in any other material but steel, which is heavier yet more lasting than plastic.

6.2.3 Bearings

All bearings used in the design and construction of the machine were picked from the McMaster catalog while keeping in mind their availability from local vendors in case replacements were to be needed in the future. All bearings were selected depending on their specific function, location in the machine and load carried.

6.2.4 Linear Stage

After estimating the weight of the finished drilling assembly a suitable linear stage was selected to withstand the torque and reaction forces created by the drilling process. The selected linear stage is a MLPS-4-10 low profile series from Servo System Company capable of supporting a 10 lbs dynamic load on a 4" travel rail. The manufacturer specification sheet is attached in Appendix I of this report.

6.2.5 Rods and Supports

After studying the shaft deflections and internal forces presented in preceding sections the shafts used were Linear Motion shafts made of AISI 1566 Steel, meeting surface finish requirements for the selected linear bearings to travel smoothly.

6.2.6 System's Driver

An automation machine technology is used to drive the four stepping motors running the vertical and horizontal motion for the Paddle Maker Machine. Rockcliff 4 axis CNC motor V10 Driver (Figure 21) enabled running the machines at low cost and high performance. The 4 stepping motors are Bi-Polar motors making the system more powerful. A bi-polar motor has a single winding per phase, unlike a uni-polar one, which has two windings per phase. In a uni-polar motor the magnetic pole can be reversed without switching current direction, where as in a bi-polar one the current needs to be reversed in order to reverse the magnetic field. Hence, the driving circuit must be more complicated.

The four colored coded wire connection shown in the schematic diagram in Figure 22 must be carefully checked, an incorrect connection will destroy the controller. The current level can be adjusted using a potentiometer, which converts the voltage to motor output current. Stepper motor performance is dependent on the drive circuit. The motor drive can handle 30 VDC and can generate voltage and current back into the circuitry. Motor failure can occur when exceeding 35 VDC. The power source for the driver is a 12 or 24 volt power supply. The 24 volt supply will reach the speed and torque twice as fast as that of the 12 volt one.

Stepper motors step from one position to the next, and their coils are constantly energized. As a results, when running at certain speed they are prone to vibration. Motor dumper

or changing acceleration helps remove vibration. The Rockcliff driver board uses a PFD adjustment setting to help remove resonance.

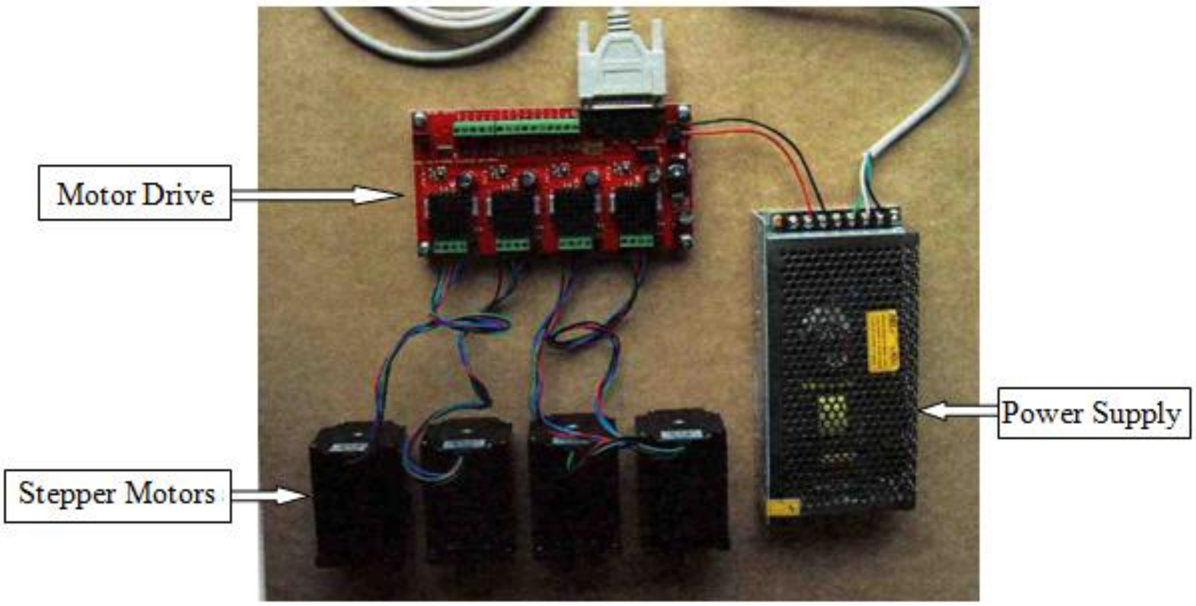


Figure 21-High Performance 4 Axis CNC Motor V10 Drive

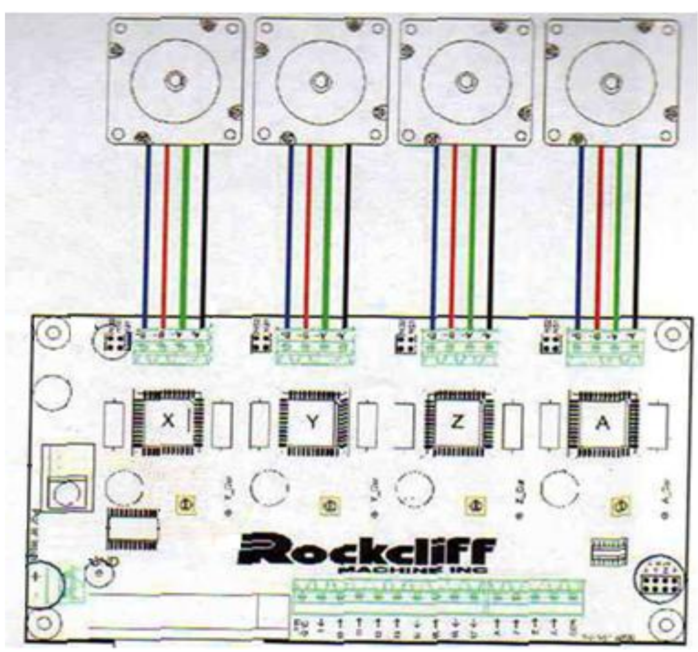


Figure 22-Schematic Diagram for Rockcliff V10

6.2.7 System's Software

PC-based CNC software, the Mach 3 series, available from Artsoft USA is used to run the Paddle maker machine. Rockcliff provides a special file name 'Rockcliff4X.XML' to configure Mach3 software settings to the motor drive board. Mach3 features and functions are easy to use. Mach3 provides tutorials that cover basic knowledge, installation and configuration, as well as many troubleshooting videos.

Mach3 minimum computer requirements are not supported by Laptops due to inherent power saving features. To use the features and run the machine accurately a desktop PC was used which outputs more consistent voltages to its parallel port pins.

One of the features provided by Mach3 is to allow us to use the G-code program language in order to move the motors up, down, left and right.

Mach3 is easy to setup, and it has many great features which are easy to understand (Figure 23). Some features used in Mach3 are: G-Code display, M-Code display, spindle speed control, relay control. The program can control Lathe, mills, Routers, Lasers Plasma and even engrave.

Figure 23-Mach3 Screen Shot Features [39]

6.2.8 Saw Assembly

A motor from a DeWALT circular saw was used to drive the carbide blade that cuts along the length of the raw material.

The following table was developed for some of the commercially available power saws. The cheapest of all these options was the third choice; however the HP of this machine is too large for the required application, thus the DeWALT Cordless Circular Saw was selected. Details of this selection are shown in table 4 and Figure 24.

Table 4-Power Saws Comparison [38]

Company/Product name	Part #	Price ($)	Voltage(V)	Current(A)	Speed(RPM)	cutting	Power(W)	Power(HP)
Kett Electric Plastic Cutting Saw	KS-224	353.77	120	5	2500	Plastic	600	0.8046
Dewalt Cordless Circular Saw	DC9390K	199.99	18	2.4	3700	Plywood	43.2	0.0579312
RIGID Circular Saw	N/A	99	120	15	3000	Framing	1800	2.4138

DC390K

6-1/2" (165mm) 18V Cordless XRP™ Circular Saw Kit

Product Features

- 3,700 RPM for fast rip cuts and cross cuts
- 6-1/2" carbide tipped blade for 2x cutting capacity at 90° and 45°
- High strength magnesium shoe and upper guard provides increased durability for long-term cut accuracy
- 0-50° bevel capacity provides additional capacity for a multitude of applications
- Fan-cooled motor with replaceable brushes for maximum power and durability
- XRP™ extended run-time batteries provide long run-time and battery life

Specifications

Voltage	18V
No Load Speed	3,700rpm
Blade Diameter	6-1/2"
Bevel Capacity	0-50°
Arbor Size	5/8"
Depth of Cut at 45°	1- 5/8"
Depth of Cut at 90°	2-1/4"
Tool Weight	8.7lbs
Shipping Weight	0lbs

Warranty Information

This DEWALT® High Performance Industrial Tool comes with a warranty package that includes:

- 90 Day Money Back Guarantee
- 1 Year Free Service Contract
- 3 Year Limited Warranty

More information on the general DEWALT warranty

The DC390K Includes:

- 1 hour charger
- 18V XRP™ battery
- Carbide tipped blade
- Blade Wrench
- Kit Box

Figure 24-Circular Saw Specifications and Features [38]

6.2.9 Drill Motor

Through an extensive search of similar motors on the market and while performing tests of our own, as explained in the Design section, it was found that the motor needed to have at least 1/10 HP and 100 ounces of torque per inch. Following this criterion some commercially available motors were selected as shown in the Appendix L, yet their prices range from $300 to $400. Hence for the purpose of this prototype the motor shown below was used, in part because it has 1/8 HP and also because it was a donation from the team's sponsor: Vulcan Materials.

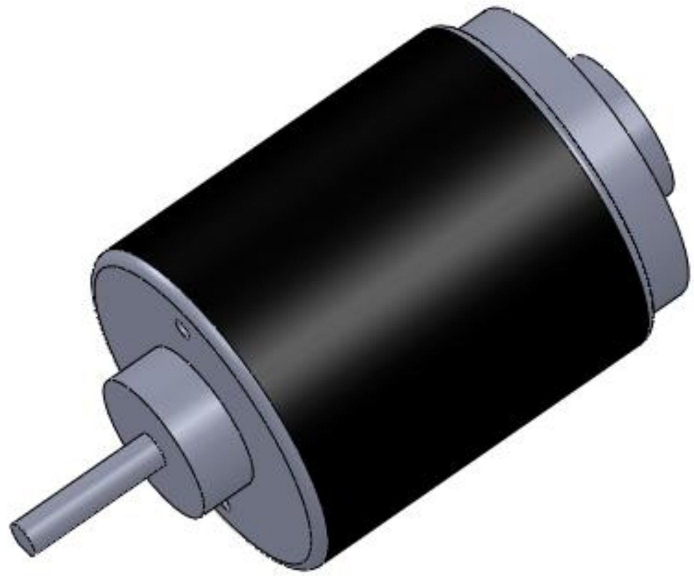


Figure 25-Prototype's Motor

This motor has a speed of 3600 RPM, thus a gear reduction system was added to the assembly to bring down the speed to about 1200 RPM, which was proven to be an effective drilling speed yielding good quality holes in this material. Two gears were purchased to accomplish this. The following drawing indicates the considerations for determining the correct belt dimensions.

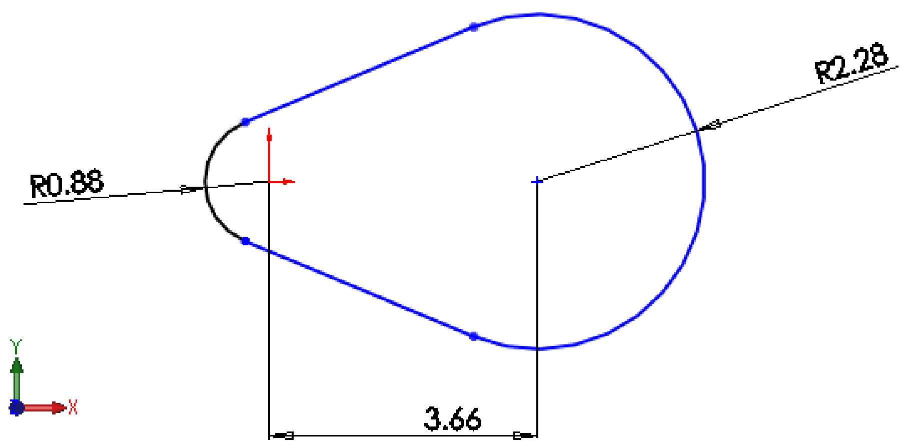


Figure 26-Belt Length Determination

6.2.10 Roller Table

The roller table was designed and manufactured to meet the size and functionality of the cutting process. Structural analyses were presented in prior sections although the table was expected to surpass design requirements, and this was proven by the large factor of safety obtained from these analyses. The roller table was designed so that the distance between rollers gradually increases along the length of the table. By doing this we are decreasing the torque required for this stepper motor to move the sheet. Thus the motor would have to work less and therefore its lifespan would likely be extended. Calculation details are included in Appendix J.

6.3 Construction

Construction of the machine was a very intensive and challenging task where our knowledge and hands-on abilities were put to the test. The roller table (Figure 27) was built by welding steels beams to form a frame 48” in length and 39” in width. Then the rollers were installed to allow for easy displacement of the raw sheet of material.

Figure 27-Roller Table

For the construction of the motor assembly (Figure 30) some elemental machining was done by one of the team members and the centricity of the gear shaft was checked using a deflection gage (Figure 28). After doing this it was realized that the gear shaft was off-centered by 0.002” due to the differences in diameter between the bearing inner cup and the shaft. A new shaft was machined to fit the inner diameter of the bearing to solve the centricity issue (Figure29).

Figure 28-Shaft Centricity Test Gage

Figure 29-Machining of Shaft to Precise Tolerance

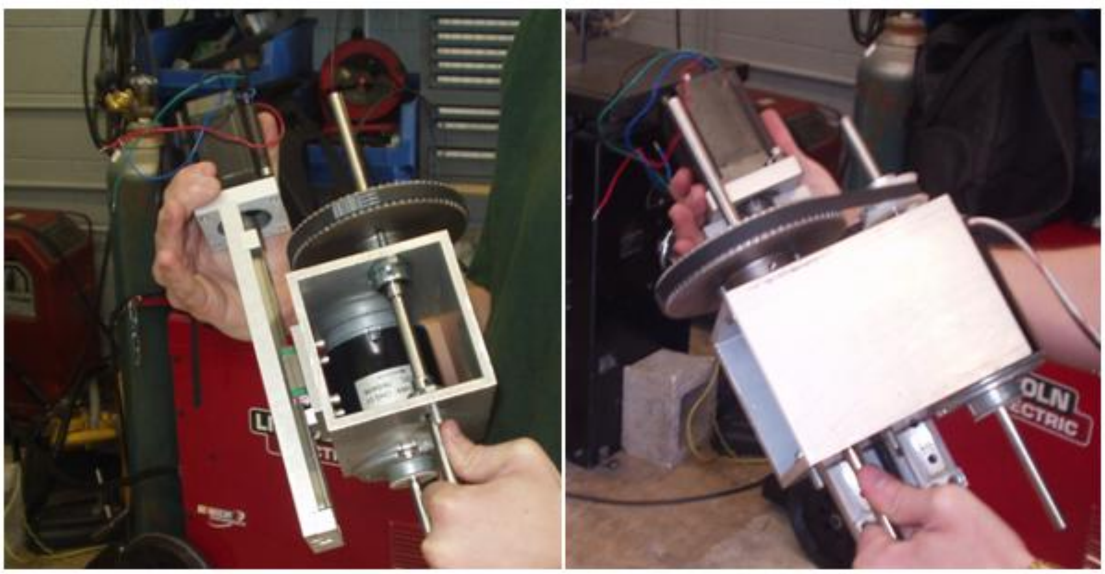


Figure 30-Motor and Linear Stage Assembly

For both the drilling and the sawing assembly two supporting rods and one lead screw attached to a stepper motor were used for movement of the assemblies. A Dewaltt 18 V circular saw was used for cutting. For further detail refer to sections 6.2.8 and 2.2.3

6.4 Prototype Cost Analysis

This section reflects the total price of buying the parts, materials and tools that were necessary for the realization of The Paddle Maker Machine.

Table 5 below represents the approximate total cost of the final design. Table 6 shows the cost analysis of manufacturing the machine using the mechanical drilling assembly instead of the drilling workstation. The reason we're showing both is that they serve as a comparison between the two main design alternatives. As can be seen by using the drilling workstation choice, a sum of around $400 would be saved. This ended up being an important factor on the decision of choosing the final design: The Paddle Maker.

Table 5-Final Design Cost

Cost Analysis			
Description	**Item Price**	**Qty**	**Subtotal**
Stepper Motor Kit	$405.00	1	$405.00
DC Motor	$350.00	1	$350.00
Linear stage	$249.00	1	$249.00
Pulley and gear	$63.37	1	$63.37
Wires and crimps	$50.00	1	$50.00
Drill Bits	$23.05	1	$23.05
Chucks			$0.00
Round rods			$0.00
Tubing	$22.84	1	$22.84
Welding Rods			$0.00
4 1/2 " Circular Saw Blade	$25.00	1	$25.00
3/8 "Corner round router	$29.00	1	$29.00
3/8" by 24' Shaft	$30.77	1	$30.77
3/8" by 8' rod	$30.00	1	$30.00
Bolts			$0.00
Linear Bearings	$143.90	1	$143.90
Ball Bearings	$19.32	1	$19.32
Flange Bearings	$45.09	1	$45.09
High Precision Rods	$50.00	4	$200.00
Polyethylene Sheet	$278.00	1	$278.00
Total			$1,964.34

Table 6-Initial Design Cost

Cost Analysis			
Description	**Item Price**	**Qty**	**Subtotal**
Stepper Motor	$80.00	3	$240.00
DC Motor	$250.00	3	$750.00
Power Supply	$200.00	1	$200.00
Wires and crimps	$50.00	1	$50.00
Drill Bits	$23.00	7	$161.00
Chucks	$15.00	7	$105.00
Round rods	$30.00	4	$120.00
Tubing	$22.84	1	$22.84
Welding Rods	$10.00	1	$10.00
4 1/2 " Circular Saw Blade	$25.00	1	$25.00
3/8 "Corner round router	$29.95	1	$29.95
V-belts	$20.00	8	$160.00
Bolts	$15.00	1	$15.00
Bearings	$20.00	14	$280.00
Polyethylene Sheet	$278.00	1	$278.00
Total			$2,446.79

Not included in these tables is the labor cost involved in this project. After having finished our project all hours related to design, construction and testing added up to be about 910 hours total, which multiplied by $20 per hour yields around $18,200 of prototype development cost. The $20 per hour rate was used in these calculations since this is the average rate per hour charged by machine shops in Miami, and is also around the average salary for in-training engineers, such as ourselves. However of this time, 208 hours were devoted to machining the different components; had the team contracted the services of Mr. Zicarelli at the FIU's manufacturing center, this time would have been decreased to about 55 hours which would have cost about $1375. If this prototype were to be mass produced then this price would be significantly reduced.

The following graph shows the approximate amount of hours that each member worked per week throughout the duration of these last two semesters. The peak represents the spring break week where the team spent about 250 hours building the prototype. The total amount of hours is as follow: Orena 389 hours; Jorge 393 hours; Nestor 396 hours.

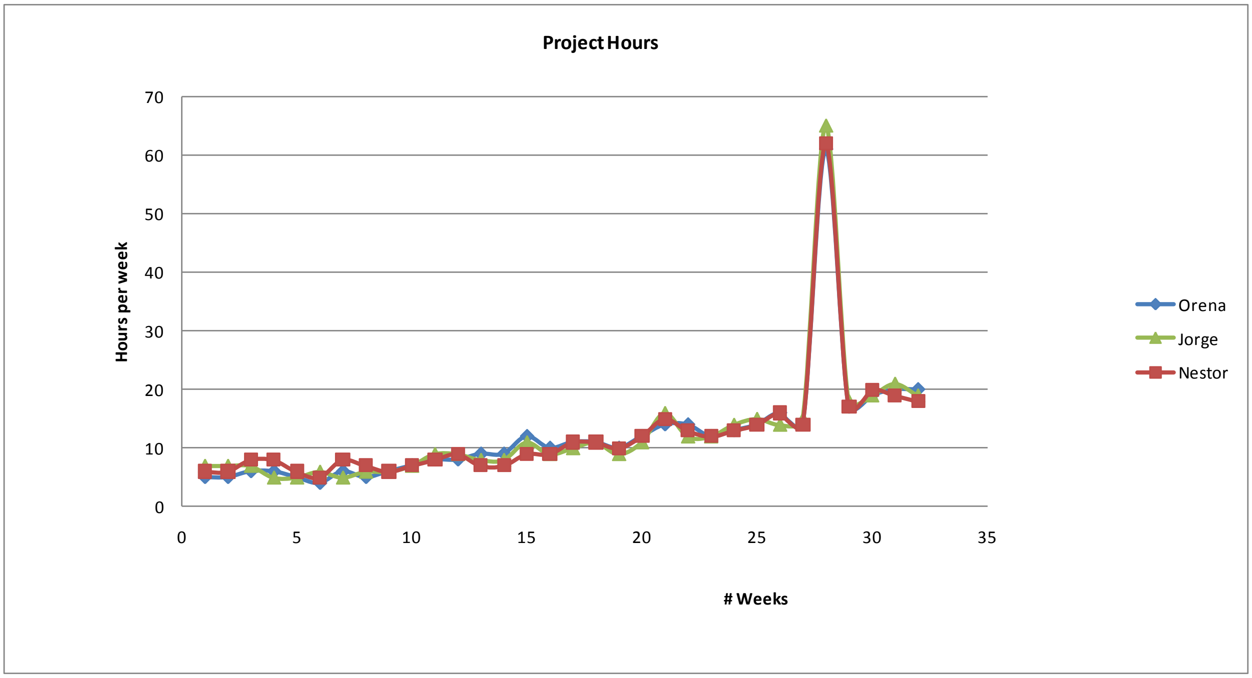


Figure 31-Paddle Maker Team's Total Hours

7. Testing and Evaluation

7.1 Design of Experiments

7.1.1 Mack 3 CNC controller Input Verification

Using Mach3 software requires motor configuration outputs for step pin number and direction pin number. Mach3 software is compatible with the Rockcliff CNC motor driver. The figure below shows the pin assignment for the four steppers motors per Rockcliff manual. The configuration is attached in Appendix R.

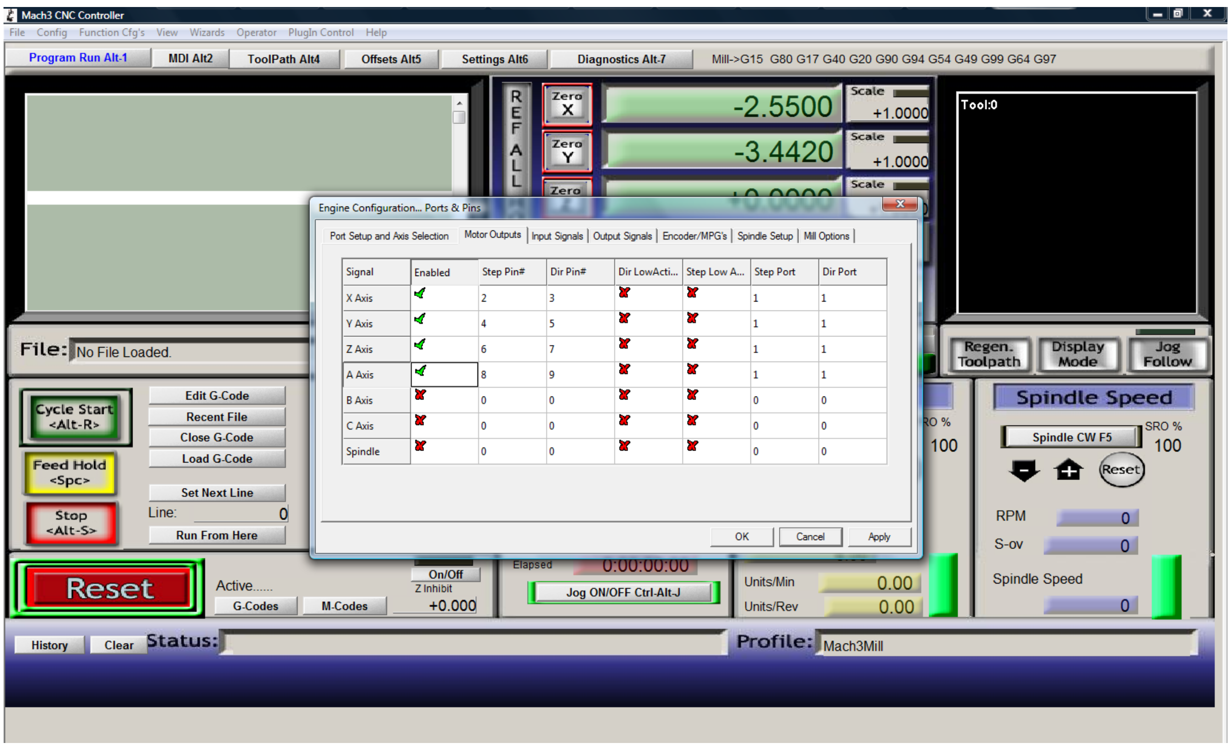


Figure 32-Conector Pins Assignment

Part of the setup was to obtain the correct velocity and acceleration for each stepper motor. Figures 32-35 below are movement profile screenshots for X, Y, Z & A axis. The X axis assigned to the drill assembly and the Y axis assigned to the saw assembly; both move in the horizontal direction. The Z axis move the drill assembly vertically, and the A axis rotates the wheels that move the sheet forward.

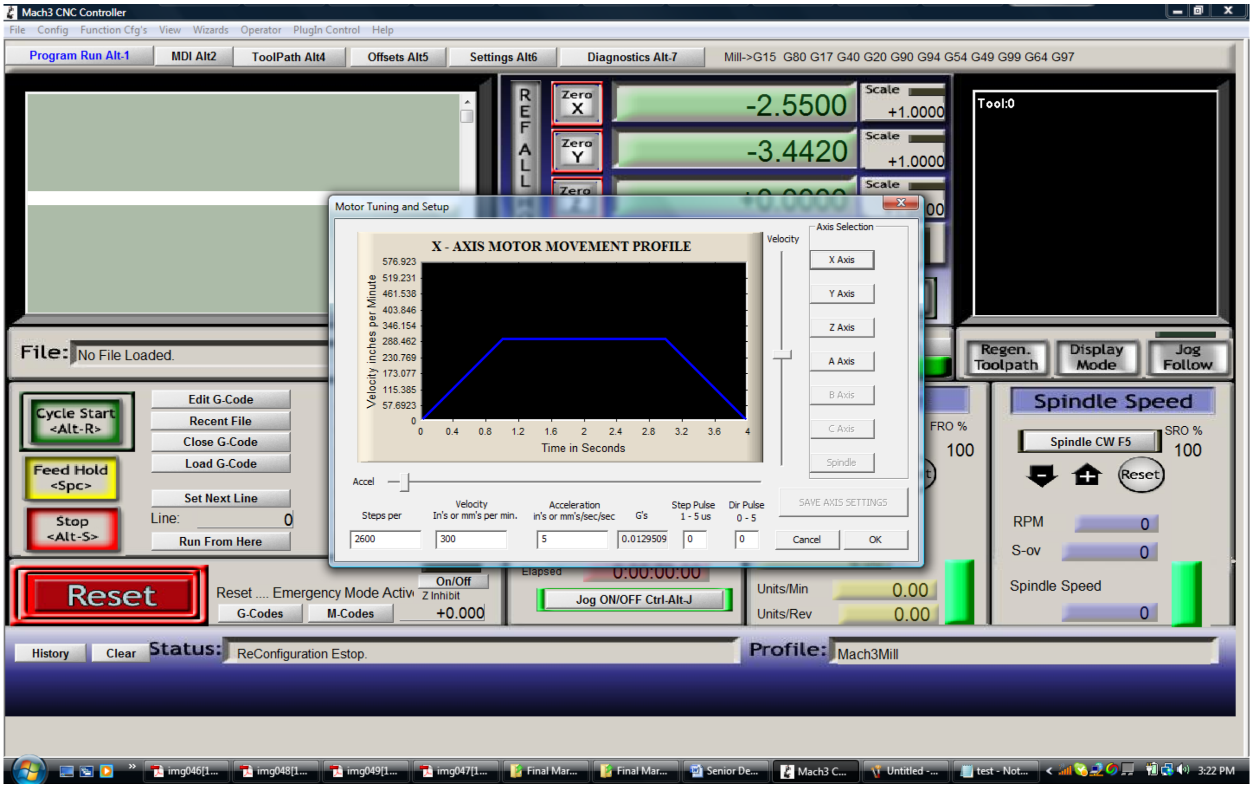


Figure 33-X-axis for Drill Assembly (Horizontal Direction)

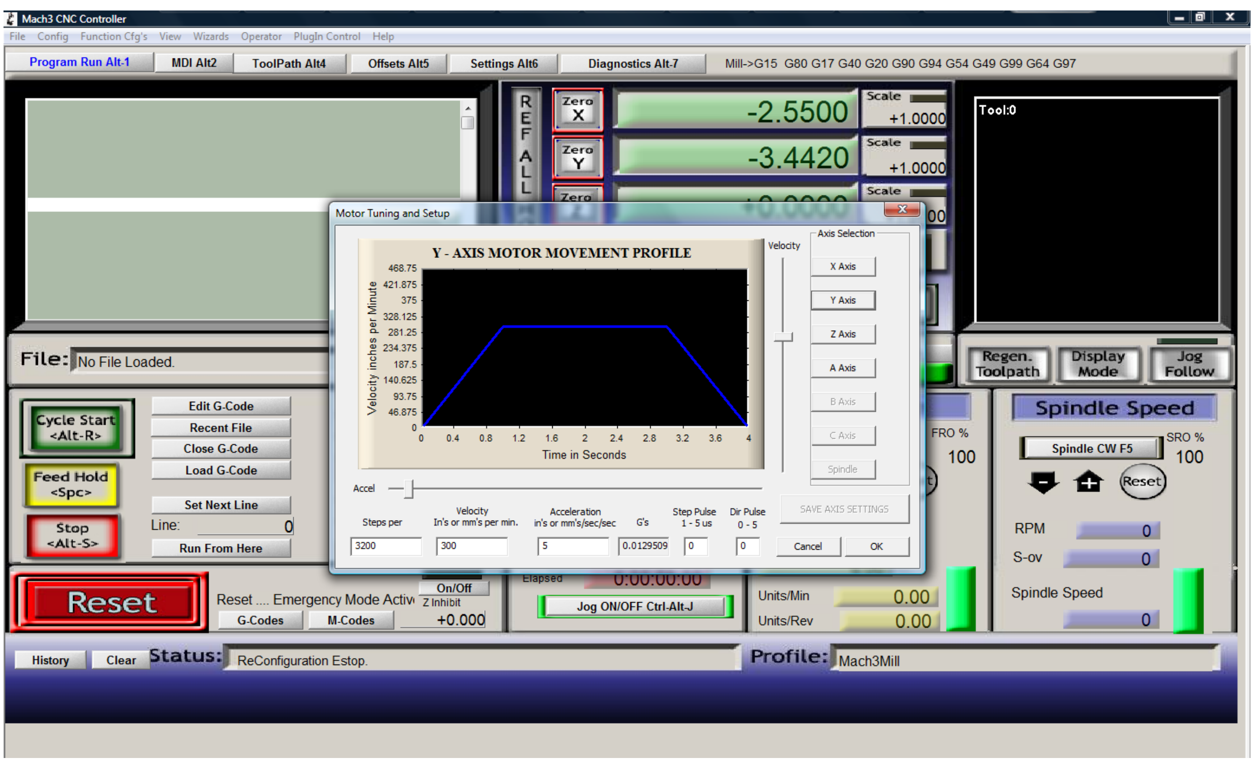


Figure 34-Y-axis for Saw Assembly (Horizontal Direction)

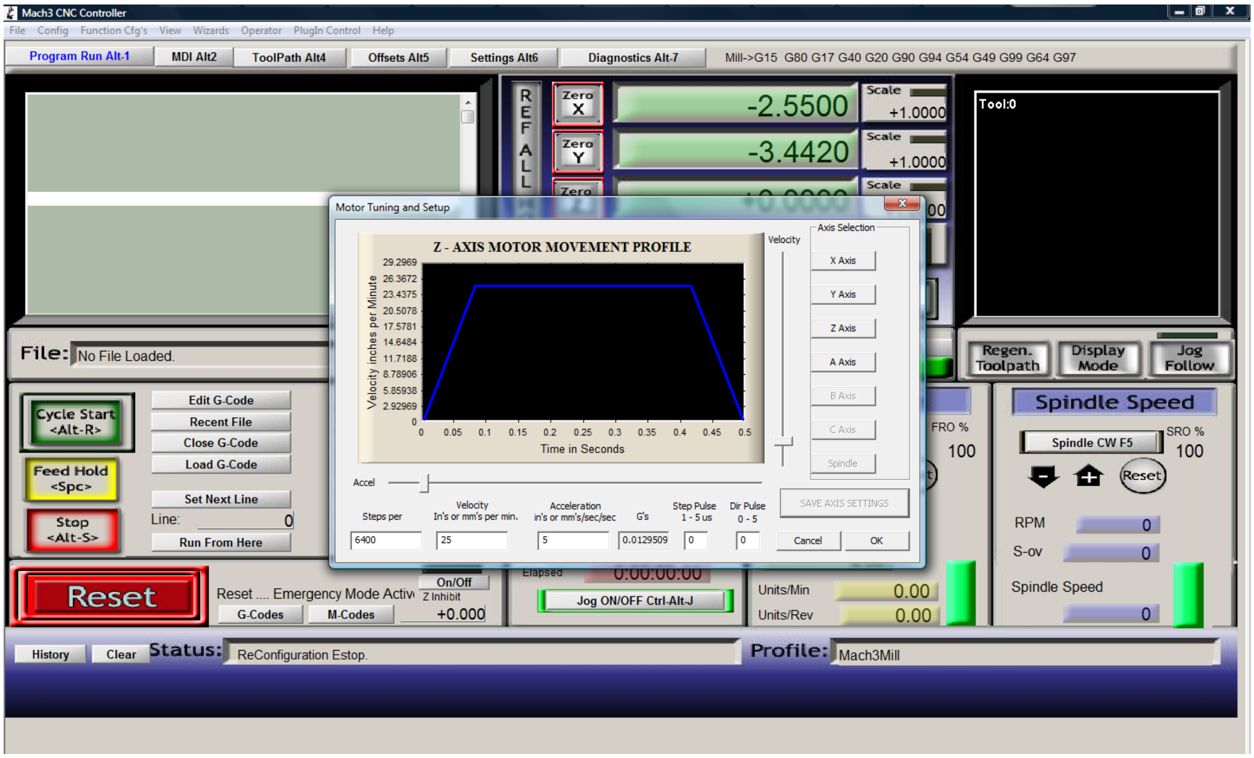


Figure 35-Z-axis for Drill Assembly (Vertical Direction)

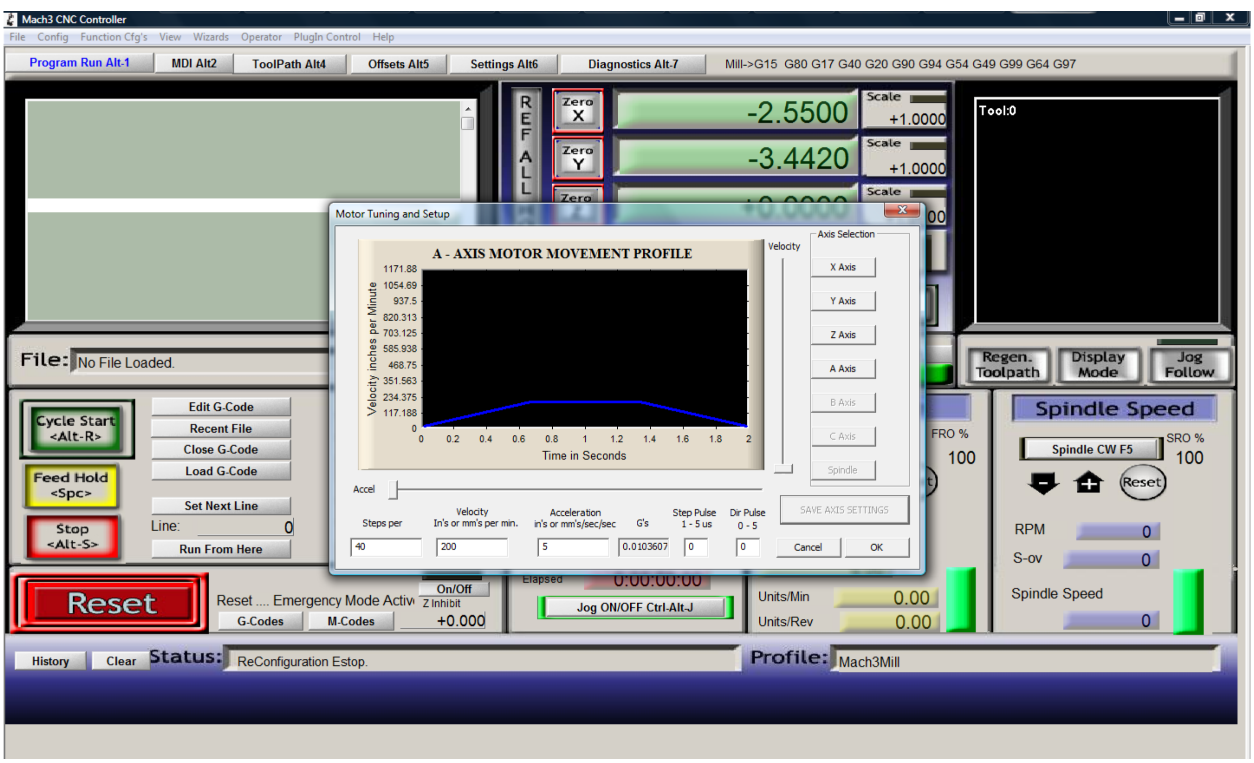


Figure 36-A-axis for Wheels (Angular movement)

7.1.2 G-Codes

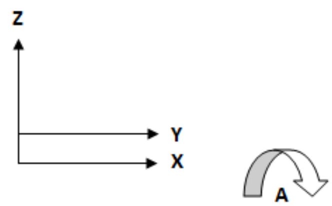


Figure 37-X, Y, Z, A Axis Positive Movement

Simple G-code shown below was written and loaded to Mach3 software and used as follow:

- The A-axis rotates in the given amount of degrees (15^0), causing the sheet to move forward the 1.75” width of paddle.
- The first hole tapping drill cycle starts at zero X and at Z= -1.5 coordinates
- The drill assembly goes up to Z= -1 coordinate
- The drill assembly moves to X= - 5.5 to second hole position
- Second hole tapping starts
- The cycle continues for a total of 6 holes. The paddle center hole is not drilled
- Cutter saw start to cut and moves Y= - 40, while the drill comes to X=0 zero home position.
- The sheet mover wheels go from an angle of 15^0 to 14^0 when saw finishes cutting to guarantee that no contact takes place.
- Saw and vertical axis Z of drill assembly goes to zero position at the same time
- Sheet mover wheels turn 16^0, moving the work piece to the correct cutting position.
- Program repeats for construction of next paddle.

PADDLE MAKER PROGRAM

g0a15(Sheet moves forward 15 degree)

(First hole tapping drilling cycle)
g0z-1.5
g0z-1.8
g0z-1.75
g0z-1.9
g0z-1.85
g0z-2
g0z-1.95
g0z-2.1
g0z-2.05
g0z-2.2
g0z-2.15
g0z-2.3
g0z-2.25
g0z-2.4
g0z-2.35
g0z-2.6
g0z-1

g0x-5.5 (Moving to second hole position)
(Second hole tapping drilling cycle)
g0z-1.5
g0z-1.8
g0z-1.75
g0z-1.9
g0z-1.85
g0z-2
g0z-1.95
g0z-2.1
g0z-2.05
g0z-2.2
g0z-2.15
g0z-2.3
g0z-2.25
g0z-2.4
g0z-2.35
g0z-2.6
g0z-1

g0x-11(Moving to third hole position)
(Third hole tapping drilling cycle)
g0z-1.5

```
g0z-1.8
g0z-1.75
g0z-1.9
g0z-1.85
g0z-2
g0z-1.95
g0z-2.1
g0z-2.05
g0z-2.2
g0z-2.15
g0z-2.3
g0z-2.25
g0z-2.4
g0z-2.35
g0z-2.6
g0z-1

g0x-22(Moving to fourth hole position)
(Fourth hole tapping drilling cycle)
g0z-1.5
g0z-1.8
g0z-1.75
g0z-1.9
g0z-1.85
g0z-2
g0z-1.95
g0z-2.1
g0z-2.05
g0z-2.2
g0z-2.15
g0z-2.3
g0z-2.25
g0z-2.4
g0z-2.35
g0z-2.6
g0z-1

g0x-27.5(Moving to fifth hole position)
(Fifth hole tapping drilling cycle)
g0z-1.5
g0z-1.8
g0z-1.75
g0z-1.9
g0z-1.85
g0z-2
g0z-1.95
```

g0z-2.1
g0z-2.05
g0z-2.2
g0z-2.15
g0z-2.3
g0z-2.25
g0z-2.4
g0z-2.35
g0z-2.6
g0z-1

g0x-33(Moving to sixth hole position)
(Sixth Hole Tapping Drilling Cycle)
g0z-1.5
g0z-1.8
g0z-1.75
g0z-1.9
g0z-1.85
g0z-2
g0z-1.95
g0z-2.1
g0z-2.05
g0z-2.2
g0z-2.15
g0z-2.3
g0z-2.25
g0z-2.4
g0z-2.35
g0z-2.6
g0z-1

g0y-40x0(Cutter saw start to cut while drill comes to zero home position)

g0a14(Sheet moves back one degree when saw finish cutting)

g0y0z0(Saw and vertical axis of drill assembly goes to zero position)

g0a16(Sheet moves 16 degrees forward)

m30(Program finished)

7.1.3 Plan and Recommendation for Material Testing

Plan:

- First, we tested the Paddle Maker, by using small samples of similar materials such as plastics and thin plywood sheet that are cheaper than polyethylene.
- Secondly, a few sample paddles of different materials can be tested against wear resistance by installing them in the Flight-Conveyor belt system.
- After obtaining a desired material sheet **Wear Resistance Test** can be conducted to new and current material using an instrument called ‘Tribometer’. The highly advanced Tribometer offers precise and repeatable wear/friction testing. The weight loss, COF and Volume loss wear properties can be measured after some time. The less volume loss, and the smaller the COF is, the better the material performs under friction.
- Last, a tensile and hardness test will be conducted.

Recommendation:

Dr. Agarwal Arvind is the head of the plasma forming laboratory located in FIU Mechanical Engineering department. The laboratory is a state of the art facility equipped for tribological wear and friction characteristic of Ceramic, Metallic, Polymer, Carbon Nanotube (CNT) Reinforced Composites and Biomaterials. He advised the group first to conduct a literature search on wear resistance, and to determine the parameters of interest. After doing a literature search, the parameters of interest for testing the UHMW-PE with the Tribometer were finalized to be:

1. All Samples needed be ¼” x 1” x 1”. The size was chosen to fit in the tribometer tester.

2. Only a brief Diamond polish was suggested since material was smooth enough.

3. Normal load during wear 10N. It is a moderate load for a soft material when compared to ceramic and metallic.

4. Wear distance: 300m. The distance will give consist data. A longer distance will wear more.

5. Rotational speed: 300 rpm or 250 rpm (Considering approximately 0.1 m/s). The speed is good for polymers were the wear loss is less than that of ceramic and metallic.

6. Wear track diameter: 6mm, Al_2O_3 ball. Time 50 min (3000sec). This will allowed conducting 2 tests for each piece.

The following properties can be obtained after testing:

1. Wear volume

2. Wear Depth

3. Coefficient of friction

The Tribometer tester in FIU plasma lab features real time measurement of friction and wear depth with a maximum load of up to 60N.

7.1.4 Theory Testing

The usage of angles on both sides of the paddle was tested since it was unclear whether having angles on both sides instead of one would make a difference on the wearing of the paddle. Thus a double angle was done manually to three of the existing paddles and they were mounted in the conveyor along with the regular one sided angle design. After a month in the conveyor all the paddles experienced the same friction and wearing action. They were dismantled from the

conveyor and three of the one sided angles were compared to the three with two sided angles. Results are shown in the table and figure below seems to demonstrate that the second angle does not contributes to the wearing of the paddle; which makes sense since this side is not in contact with the frame of the conveyor itself as opposed to the other side angle that is in contact with the moving material, in this case powder cement.

Table 7-Wear Measurements for Double and Single Angle Paddles

Measurements (inches)			
Double angle	**Left**	**Middle**	**Right**
Double 1	1.6770	1.6320	1.6560
Double 2	1.6580	1.6270	1.6655
Double 3	1.7075	1.7020	1.6625
Single angle			
Single 1	1.6455	1.6325	1.6385
Single 2	1.6920	1.6565	1.6710
Single 3	1.6625	1.6690	1.6365
Original			
New	1.7500	1.7500	1.7500

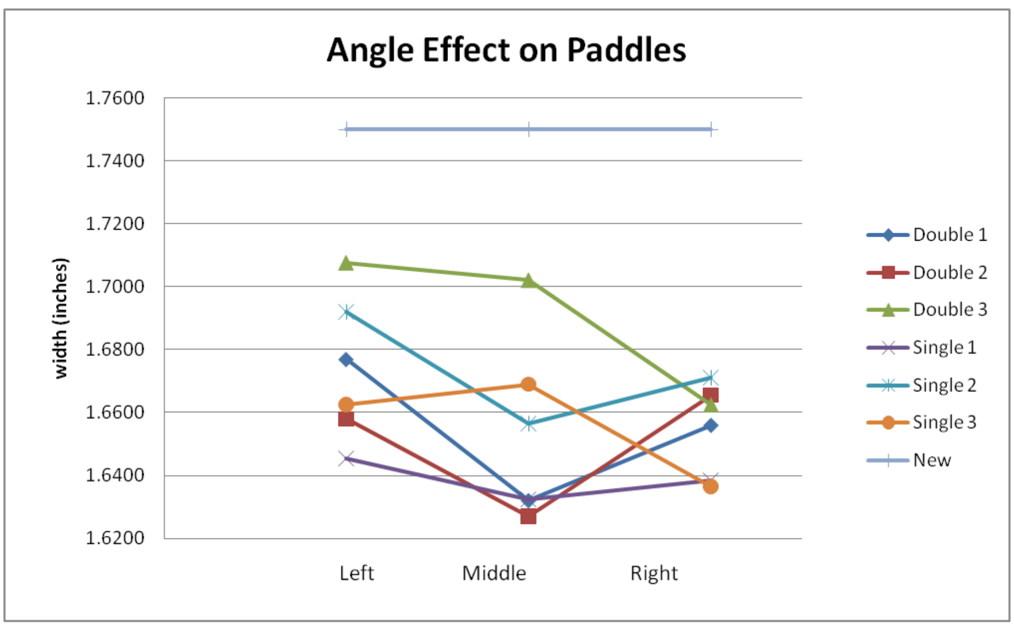


Figure 38-Double Angle vs Single Angle

7.2 Test Results

7.2.1 Paddle Material Comparison

An extensive search for an improved wear resistance ultra-high molecular weight polyethylene sheet was conducted. The Gund Company is the current paddle supplier for RBT. It is also the current vendor for the new and improved purchased material. A UHMW-PE sample with crosslink process was obtained from the Horn Plastic Inc. Those three different materials were tested, and their wear resistance properties compared.

Material:

Three physical properties for three different samples (Figure 41) were compared: Tensile Strength, Modulus of Elasticity, and Hardness.

The *current* UHMW-PE used by RBT Company obtained from the Gund Company.

Physical Properties are:

Tensile Strength 2,500 PSI.

Modulus of Elasticity in tension 1.02 x 10^3 PSI.

Rockwell Hardness R38.

A *purchased* improved UHMW-PE from the Gund Company.

Physical Properties are:

Tensile Strength 5,500 PSI.

Modulus of Elasticity in tension 116 x 10^3 PSI.

Hardness, Durometer, shore “D” scale 68.

A purchased crosslink UHMW-PE sample from the Horn Plastic Inc.

Physical properties are unknown. Color is Orange.

Procedure:

1. Two pieces of each material were cut to length of ¼” x 1” x 1”.

2. Samples were diamond polished for a very short time. This was done in FIU AMRI Lab.

3. A Tribometer Tester (Figure 39 and 40) located in FIU plasma lab was use to test and compare wear resistance.

4. Test parameters:

- Normal load during wear: 10N
- Wear distance: 300m
- Rotational speed: 300 rpm or 250 rpm (Considering approximately 0.1 m/s)
- Wear track diameter: 6mm, Al_2O_3 ball
- Time 50 min (3000sec)
- Calculation for time and rpm:

$$Time = \frac{Distance}{V} = \frac{300m}{0.1\frac{m}{s}} = 3000s$$

$$rpm = \frac{Velocity}{\pi * Dia} = \frac{0.1^{m}/_{s} * 60s}{\pi * 0.006m * 1min} = \sim 300rpm$$

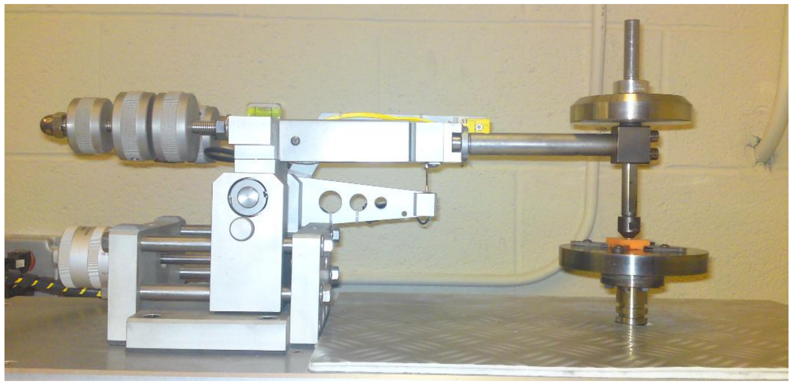


Figure 39-Tribometer Tester Setup

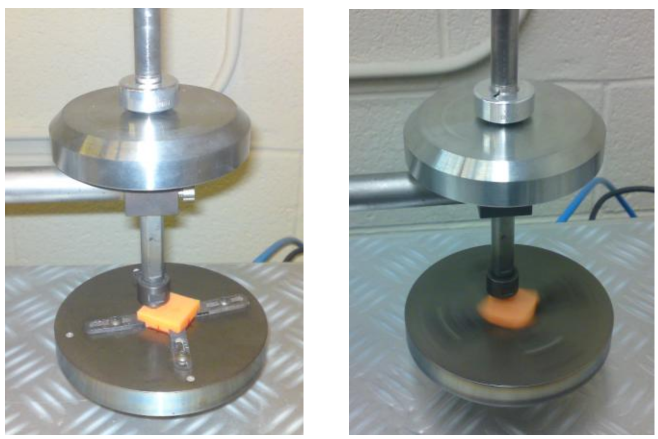


Figure 40-Ceramic Abrasive Ball on UHMW-PE Disc Test

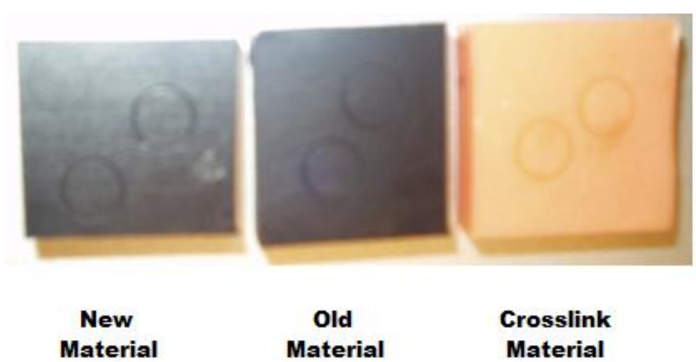


Figure 41-Tested Samples

Results and Data:

Lab notes for weight loss obtained during test are in Appendix M. Excel data for all tracks are included in the CD. Excel data result in Appendix N contains only a sample of 50 data points out of 52,260. The Nanovea software for the tribometer tester gives 15 to 20 data points per second. Total time for each track was 50 minutes. The software displays values of distance (meters), Coefficient, and Ceramic ball Depth (mm).

The two graphs below show wear volume loss, and coefficient of friction values for all three samples: Old Material, New Material, and Crosslink Material.

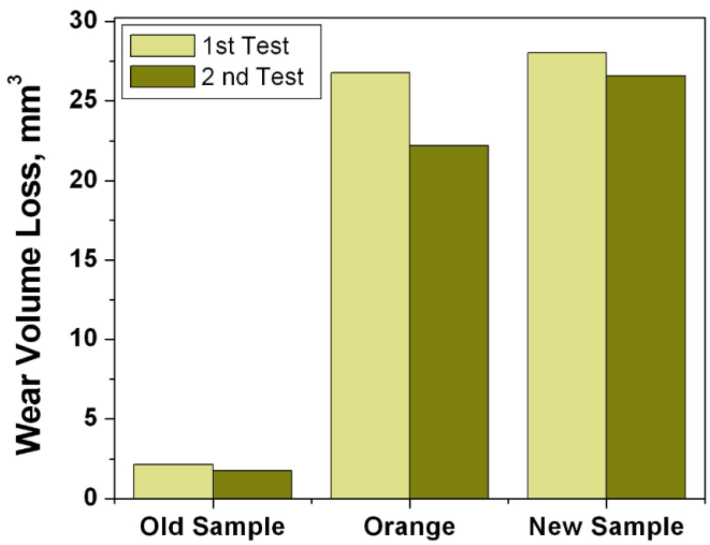


Figure 42-Wear Volume Loss Comparison

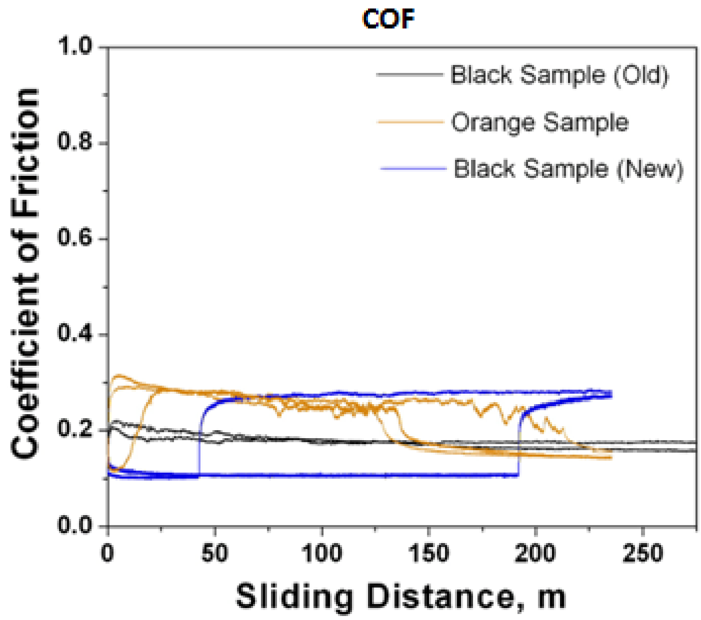


Figure 43-Coefficient of Friction Comparison

7.2.2 Paddle Maker Calibration

Calibration of the machine was done to assure that the right functioning of the Paddle Maker was obtained. Through Trial and Error, all the stepper motors were calibrated, so that the optimum speed and movement's distances were achieved. It took a few paddles for the machine to get calibrated, but the end result was a coordinated machinery where all subassemblies worked together as one. Paddles produced by this machine were of good quality and accuracy.

7.3 Evaluation of Experimental Results

7.3.1 Material

When testing different materials using a tribometer, coefficient of friction, weight loss, and volume loss can be measured and compared. Comparing these parameters shows which

material has better wear resistance characteristics. Using the tribometer tester in the plasma lab at FIU data for three samples was obtained and compared.

Volume loss formulas are shown in Figures 42. Volume data was obtained from excel using LVDT column for depth *h*. The LVDT gives voltage signal when there is a small displacement. The *h* data points were calculated as follows:

- The first points, up to where the graph starts having a trend of steady state, were not considered because in the beginning of the test there is a transient higher friction causing an increase in the curve.
- Next the average data points of the first minute, after steady state starts, were subtracted from the last minute (the 50th minute).

$$V = A * L$$
$$L = 2\pi r^{*}$$
$$A = \frac{nR^2}{2} - r(R-h)$$
$$n = \sin^{-1}\frac{r}{R}$$
$$r = (R-h)\sqrt{R^2 - (R-h)^2}$$

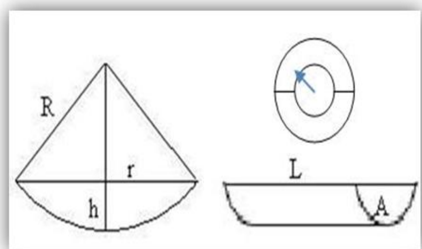


Figure 44-Volume Loss Formulas

Where **V** - is wear volume loss.

A - is the area of sector minus triangle.

R - is the radius of Alumina ball.

r* - is the radius of wear track.

h - is the average depth (obtained from software data points)

L - is the track length

n - is the angle of the arc sector

Weight loss the data shown on the lab notes in Appendix N obtained using a scale before and after each track. The scale measured in micro grams (0.0001).

Coefficient of Friction (Figure 43) obtained from the Excel data sheet.

Results:

COF Results:

New sample:

- Up to the first 50 meters (Figure 43) the values are the lowest for both tracks when compare to the other samples.
- The values increased much higher for the second track only after the first 50 minutes.

Orange sample:

- The values are the highest of both tracks

Old sample:

- Trend is similar for both tracks. The average COF is similar in value.
- For the first 50 meters the values are higher than those of the new sample

Weight Loss Results:

- The data shown similar weight loss for both new and old samples.
- There is an "increase" in weight loss for the cross link material.

Volume Loss Results:

- The sample data for volume loss was as follow:

  Old sample

  2.14 mm^3, 1.74 mm^3

  New sample

  28.00 mm^3, 26.54 mm^3

Orange (crosslink) sample

1.65 mm^3, 22.19 mm^3

Because of the difference in the volume loss values for the orange sample another track test done and volume loss measured 26.76 mm^3

Figure 42 depicts a lower volume loss for the old material when compared to the new and cross-link material. For each sample, old and new, both tracks were similar in values. The Orange sample had one low and one high value and the test was repeated one more time. The third test had high value. Only the higher values were considered for the orange sample. It could be some experimental error which gave such lower value for the first test.

Discussion and Conclusion:

In general, a lower COF and a lower volume loss, shows better wear resistance. The results comparison for the three samples was not as expected. The Cross-linked and the new material samples have higher COF and higher volume loss than that of the Old material. However the weight loss measurements showed an increased in value and questions arose about the test method. After further research about the subject we understood that the UHMW-PE material does not always experience weight loss when using the ball on disk type test. Sometime it is just compressed and the density is increased. In addition, because a load is applied on the sample during the tribometer test and therefore compressed on the material, a question about accuracy of the LVDT (*h*) values was raised.

Regarding the results for the cross linking material, in order to get a constant coefficient of friction the molecular bonding should be good. Since data sheet for the crossed-linked sample

was not available from the vendor a conclusion can be made to exclude this material as a comparison.

Regarding the new and old material, when buying it from the vender one cannot be sure of the preparation and process the polymer was exposed to or if the material is homogenous or not.

In conclusion, even though the COF is not that important, the concern is with the total volume loss. With the ball being compressed and with the results not as expected, the conclusion was that the volume loss data might not be accurate. Thus, a different method of measurements needed to be obtained and is illustrated in section 7.4.1. Also, since polymers have good bonding and can be compressed, whereas a ceramic material, for example, wears out because of poor bonding, a different test method such as pin on disk and not a ball on disk must be considered for the obtained polymer sheet. A Pin on disk abrasive type test method, where the pin is made of the UHMW-PE and the disk is made of Aluminum oxide, will be closer to wear conditions.

7.4 Improvement of the Design

7.4.1 Material Wear Resistance

The results shown in Section 7.2 and 7.3 prove that a search for a better wear resistance material and a use of a different kind of test must be followed up. It is clear from the literature survey and many studies done on that subject that cross-linked process on UHMW-PE can improve wear resistance. The cross-linked sample tested in this experiment was shipped to us at no cost and did not have any data sheet available. We contacted Electron Technologies Corporation (ETC), a 47 year irradiation processing provider in New England, to ask their

expertise on how to improve wear resistance for UHMW-PE. The information gathered made clear that research and development for different radiation doses on different samples must be obtained and tested. In general, irradiation can improve the physical properties of cross-link bi-section, or can degrade and make it brittle. Hence, depending on the level of the cross-linking will give different physical properties. Radiation will increase the melting temperature and will make it more solvent resistance, and a better heat resistant.

In ETC R&D facility they will apply three different radiation doses of 2.5MR, 5MR and 7.5MR. Testing of those samples, will determine which doses improve wear volume and COF. However, the cost for one hour lab in R&D at their facility is $400. Since the budget is limited it will be left for future evaluation. Additional information gathered from ETC about the price was that once the radiation doses will be determined by us the cost for production at their facility will be $20 per sheet.

Since the data obtained with the current ball on disk volume measurements were not as expected, and since we concluded that this test is inappropriate for the polymer in use, three approaches to measure the depth of the tracks were considered, as well as one different test method.

1. The three samples tested using the tribometer were cut vertically across the tracks using a diamond cutter, and the depth of the track was measured using an optical comparator. Those tools are available in AMRI lab in FIU. However, the high speed diamond saw was out of order so this method was not an option.
2. The Profiliometer tester located in AMRI lab (Figure 45) was used to measure surface roughness. Using the Stylus 12.5 μ curved tip contact to measure surface roughness.

Figure 45-Profiliometer

Parameters input:

- 2000 µ m (2 mm) length of scan
- 0.2 samples per µ
- 8 sec

Output:

- Δ- average between upper and lower surface (Figure 45)

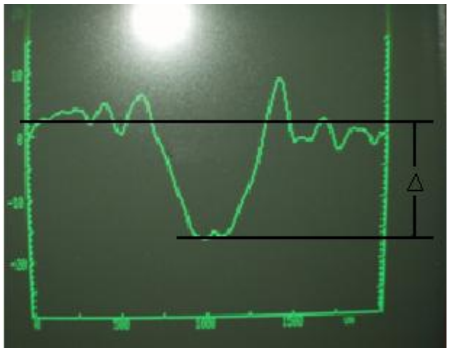


Figure 46-Average Delta Surface Roughness

Results:

There were inconsistent results measuring the same track. This relates to the fact that the assumption is that the roughness outside the groove is at the same level. The stylus is a technique for a smoother surface. Figure 47 depicts how the applied force pushed the material more

towards the track inner circle when using ball on disk tester. Hence, it is difficult to decide where to take the average when the surfaces outside of the groove are not at the same level. Also, the drop down groove of the tested sample is barely wide enough for the 12.5 micron Stylus technique. The stylus has to travel some distance to give accurate results rather than just going through a narrow groove.

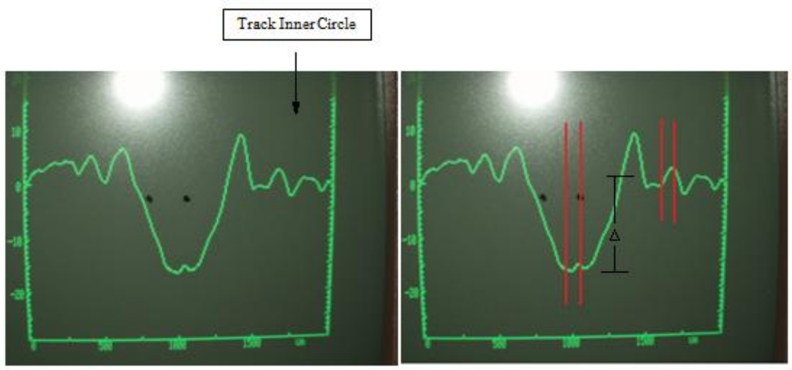


Figure 47-Uneven Roughness

3. An Optical Magnification Microscope

Figure 48-OMM

MX40 Olympus Optical Magnification Microscope (Figure 48) was used as other technique to measure the track depth of the three samples. The upper and lower grooved surface was measured using a focus adjustment gradation of 0.1mm minimum per increment.

Input:

- A 2000 Magnification

Output:

- New sample:

  -First track measured average difference of 16 between upper and lower surface

  -Second track measured average difference of 13 between upper and lower surface

- Old sample:

  -First track measured average difference of 17.5 between upper and lower surface

  -Second track measured average difference of 20 between upper and lower surface

- Orange sample:

  -First track measured average difference of 33 between upper and lower surface

  -Second track measured average difference of 18 between upper and lower surface

Results:

Smaller numbers mean the groove is less deep and therefore less volume loss. With the Optical Magnification Microscope the new samples exhibit smaller volume loss; just the opposite of the results that were obtained by calculation the volume loss using the tribometer. (Appendix M – lab notes)

4. A Pin on Disk test mentioned in the literary survey is being considered as an alternative to the Ball on Disk test. Here the Pin is made of UHMW-PE and the Disk is made of Aluminum Oxide Ceramic abrasive material. The weight loss will be measured in the same manner as in the Ball on Disk test where the pin - and not the disk - is weighted.

The Optical Magnification Microscope depicts that the new samples has the smallest volume loss and not the old sample.

After using the optical microscope one can conclude that with a groove making technique (ball on disk) there is a wide range of results between the same sample (comparing the two tracks) and between the old and new material. In the tribometer tester a load is applied on the sample, and after taking out the load there is an elastic recovery of the material. The ball is forced to go down while measuring the depth, but after the test is done the ductile material relaxes and deforms back. That makes the LVDT less accurate, and therefore unreliable. When using metal and ceramic material as discs, volume data is more accurate. In addition, with the ball on disk method, local temperature causes the material to melt and deform. Melting can increase the contact area of the ball, and this causes the friction force to increase. This might be the explanation for the uneven roughness surface depicts in Figure 47 when using the Profiliometer.

7.4.2 Overall Machine Components and Design

In the current design simple threaded rods are used to aid the drilling and sawing stations to move in the horizontal direction. In order to improve the travel distance and speed of the assemblies a precision lead screw from Grainger catalog (Appendix P) with ½ inch travel pitch will have to be purchased. The cost for two lead screws, one for the drill and one for the saw is $320.

The maximum speed for the stepper motor in the current design is 950 RPM. Each assembly has to travel a horizontal distance of approximately 45”. If a new lead screw, of 1” pitch, is purchased, it will take 2.84 sec for the saw and drill to travel the 45”. Figure 49 shows comparable calculations for the time it takes when the lead screw comes with 1” and ½” travel distance per revolution.

For 1 inch travel per revolution

$$\frac{950\ RPM}{60\ sec} = \frac{950\ inch}{60\ sec} = \frac{45\ inch}{X} \rightarrow X = 2.84\,\text{sec}$$

For 1/2 inch travel per revolution

$$\frac{950\ inch}{1''} = \frac{X}{\frac{1}{2}\ inch} \rightarrow X = 475\ inch$$

$$\frac{475\ inch}{60\ sec} = \frac{45\ inch}{X} \rightarrow X = 5.68\,\text{sec}$$

Figure 49-Travel Time Using Precision Lead Screw

8. Design Considerations

8.1 Assembly and Disassembly

In every mechanical system where wear and tear exists, the design challenge brings the concern of flexible and fast maintenance. It is a fact that at some point in the life cycle of any machine, maintenance will have to be performed to its moving components; consequently the gaining easy access to these components that require maintenance is a characteristic that concerns every user. Easy access means less time spent maintenance is done to the machine, therefore saving money and down time. The flexibility of replaceable parts is a key feature as well, particularly for those parts in contact with the product being handled. For these reasons most of the components of the machine were designed to be attached with bolts for easy disassembly, replacement and assemble process. The only component of the machine that was permanently welded is the table structure, which is expected to have lifetime durability under normal operating conditions.

8.2 Safety and Maintenance Procedure

The Safety Information Manual is attached in Appendix G. It includes general safety information for machine shop usage of such a machine. It is clearly stated in this manual that all personal working with this machine must follow the safety rules explained therein. Failure to follow instructions can result in severe injury or death. OSHA [25] code violations must be followed. Also it is mentioned that only authorized trained personal should operate the machine.

The manual is divided into four sections:

- The 1st section is general machine shop safety information.
- The 2nd section includes conveyor safety information, operation and maintenance.

- The 3rd section contains table saw safety information, operation and maintenance.
- The 4th section includes drilling safety information, operation and maintenance.

In addition, the safety manual includes all warning and hazards signs to be displayed in the shop to assure personal awareness.

8.3 Environmental Impact

An assessment of the possible environmental impact of chemical or hazardous materials being used must be taken into account while constructing a machine. The impact can have positive or negative social and economical aspects.

Grease will be used to lubricate the machines' components. In addition, drilling holes through plastic sheets, and the scraping corners of the paddles will create a great deal of chips. It is our responsibility as engineers to promote a clean environment by recycling the chips, and ensuring the use of non hazardous lubricants that will not cause severe health problems.

EP-2 lubricating grease will be used to lubricate the components. The machine will need to be lubricated every 250 operational hours. It is a petroleum based mineral oil, which can cause slight irritation when in contact with skin. The major environmental impact to be considered relates to oil waste. Grease should not be disposed into water. When it floats on water it eliminates the oxygen from being transport into the water and hence causes death for fish and other marine life. It is the user's responsibility to dispose the grease in according with state regulations and use approved containers meeting OSHA requirements.

All plastic chips generated from the machining of the paddles will be recycled. Plastics are a man made product, and therefore it can and must be reused. A recycling program from an

vendor specializing in this field should be employed by the user so the machine will not have a negative impact on the environment.

8.4 Risk Assessment

In the United States, machine safety and healthful working conditions for employee are regulated by Occupational Safety and Health Administration (OSHA). This administration provides information on installation of machine safety and proper guarding. A few organizations have their own regulation; however those must as be firm as OSHA standards. In addition to OSHA, other organizations such as the American National Standards Institute (ANSI) provide information on construction, care and use of machine tools. This information is published as B11 standards. Certain standards are developed for specific types of machine tools. Standards in the B11 series that are related to this project include:

B11.1: Mechanical Power Presses

B11.8 Drilling, Milling and Boring Machines

B11.10 Metal Sawing Machines

Purchasing the "ANSI B11.XX Machine Tool safety Package" is expensive. Therefore a Safety Manual, attached in Appendix G, includes safety information that was gathered using OSHA website and related links. Also, FIU Machine shop safety manual was used as a reference.

Safety Information Manual for the Paddle Maker Machine is attached in appendix G. It includes instruction for Installation, Operation and Maintenance on Conveyor, Drilling and Sawing operations.

Conveyors are one of the best productivity tools available to warehouses, and industrial facilities. However, employers are losing millions of dollars each year due to conveyor related injuries. The United States Department of Labor Bureau of Labor Statistics reports around fifty workplace fatalities a year where conveyors are the source of injury. In general, conveyors are safer than other material handling alternatives if they are maintained and designed properly. To address the concern of conveyor related injuries the safety information below must be considered by the employers:

1. Since guards make up one the most common types of safety devices used for the protection of conveyors, they have to be maintained regularly. In addition warning signs must be readable.
2. Conveyors operate using power transmission. Items such as gears, shafts, and belts are common to all conveyors; therefore they must be guarded from exposed power equipments to prevent accidents.

Typical items to be guarded include:

- *Drive Guards for chain, v-belt, and gearing*. Guards can be constructed of different materials such as: expanded metal, solid sheet metal, and plastic. They must be securely fastened to the conveyor framework.
- *Coupling Guards* to be provided when they are used to connect shafts. They must be assembled around the connections between motors and gearboxes.
- *End Shaft Guards* – They must be assembled in order to prevent items from becoming caught in shafts. In particular, the protruding ends of the rotating shafts are dangerous.

A table saw is one of the most dangerous pieces of equipment in a workshop. An increased awareness for caution is needed while working with a saw blade. This sharp, multi-toothed blade usually spins at high rpm therefore care is required when working near the blade. According to the US Consumer Product Safety Commission there are approximately 60,000 injuries each year related to saw blades. Another cause of table saw accidents is what is called 'kickback'. Kickback happens when the blade catches the material and throws it back towards you. Kickback can be caused by a variety of different things including:

1. When the blade is pinched by an internal stress in the work piece.

2. The work piece moves up or sideways during a cut

3. The material is pinched between the rear of the blade and the fence.

4. Underpowered saw.

It is very important to minimize the potential saw blade injuries occurring. This can be done by applying the safety rules when working with such a machine.

The Paddle maker machine includes an automated drilling operation, run by step motors and using a drill bit. The drilling operation will allow us to drill a defined hole into or through an UHMW-PE work piece in a very repeatable manner. However power drills can cause severe injuries. According to U.S. Consumer Product Safety Commission data for year 2003, approximately 4,100 people received hospital treatment for power drill related injuries.

A video named "E-061Saws/Grinder/Drill Press Instruction" is available from the ANR Environmental Health and Safety Library at *http://safety.ucanr.org.* To avoid accidents, the

operational safety rules attached in Appendix G must be observed and understood by everyone working on the Paddle Maker Machine.

9. Conclusions

The main objectives of this project were to design and construct a prototype of a machine that will manufacture paddles for a specified application and to explore the properties of the material being used to manufacture these paddles in the search for a material with better performance. The theoretical design of the prototype was not very complex. With the assistance of several computer software and the knowledge acquired in the course of our studies, the most relevant engineering analyses were conducted and the results are presented in this report.

The final prototype was decided upon after analyzing all the alternatives discussed in the Design Alternatives section. After considering all factors of interest, it was decided to build the presented design, which was called "Paddle Maker". This decision took into account aspects such as: machine cost, production cost per paddle, design reliability, part availability, construction time, environmental impact and safety.

After all the dedicated work by each member of the team was combined, the results can be seen on a functional machine that performs the required tasks. The team realizes that there are still several aspects of the project that can be improved such as changing the whole thread rods by lead screws, and replacing the drill motor by a more suitable one. This would allow for smoother running of the system and as a result the production time will be decreased and the machine and motor life extended.

Further testing and optimization of both the paddle and the Paddle Maker are an ongoing process, since there are a few suggestions that can be implemented as explained in the Future Work section.

Several comments can be stated as well in relation to the material study. Although the results were not as predicted, the test gave us in depth understanding of the behavior of polymers and their wear properties. The ball on disk is a test widely used for metal and ceramics. In this case of testing the UHMW-PE, several phenomena like melting and plastic deformation seems to affect the wear volume which explains why the results are not as expected knowing tensile strength property.

There is a need to confirm the results through other test method such as hardness and pin on disk abrasive type. In addition, more statistical data is required.

A further search for better wear resistant materials such as study effect of radiation doses on the wear property should be followed.

As a group of prospective engineers, extraordinary effort was taken by all members of the team to finalize the design and construction of a functional machine within the time limit presented in the Timeline chart, as well as to find a material with better performance than the existing one.

10. Future Work

Even though the prototype has already been finished, and it is working, some parts can be replaced to improve the overall efficiency, quality and performance of the machine.

- The two whole thread rods moving the drill and saw assembly should be replaced with lead screws (Appendix P) to improved accuracy, production time and lifespan of the machine.
- A round corner router needs to be added to the saw assembly so that the side angle can be obtained; since it will be mounted in parallel to the saw, the same stepper motor will move the whole assembly.
- Most raw material suppliers provide sheets of up to 102 inches long; therefore the rolling table could be extended to handle longer sheets of raw material.
- The circular saw blade used in this prototype should be substituted with one especially made for cutting soft plastics (Appendix F) that would provide a better finished cut .
- The drill motor can be replaced with one that is more suitable for that task, as shown in Appendix L, thus increasing the durability of the machine, yet rising its price.
- A system that would allow for the collection of the produced paddles needs to be developed so that production of many paddles can be achieved in an organized and fast manner. The team proposes to built a slider mechanism that would attached to the end of the machine where paddles are output, and through which the paddles will slide down to a collection table.
- All the electronics should be optimized by electrical engineer since it was designed using elemental knowledge of circuitry and electricity. The main elements that need to be looked at are the wire sizes, power supply selection and motor efficiency.

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12. Appendices

Appendix A-Paddle Material Data Sheet

The two following data sheets were obtained from the user manual of the RBT.

The Gund Company, Inc.
St. Louis, Missouri

Tel: (314) 423-5200
Fax: (314) 423-9009

Material Data Sheet

Item: Polyolefins

Description: A class of plastics produced as Low and high Density Polyethylenes, Polypropylene, and Ultra High Molecular Weight Polyethylene (UHMW). Low Density Polyethylene (LDPE) is an excellent material for chemical uses in low heat applications providing good toughness, resistance to chemicals, and flexibility.
High Density Polyethylene (HDPE) is more rigid than LDPE, approximately 4 times more tensile strength and 3 times more compressive strength. HDPE satisfies FDA requirements for direct contact with food. HDPE is accepted for USDA and NSF applications, including use for meat cutting boards.

Polypropylene (PP) is lightweight, has high tensile strength, impact resistance, and resistance to most alkalies and acids. It is non-toxic with low moisture absorption. Applications include die cutting surfaces, tank linings, cutting boards, gasketing and Prosthetic devices. LDPE, HDPE, and PP are thermoformable and require welding vs. glueing when fabricating.

Ultra High Molecular Weight Polyethylene (UHMW) has the highest impact strength of the Olefins, providing a very low coefficient of friction requiring no lubrication. It also has extremely low moisture absorption. It is an extraordinary material for industrial uses in wear and sliding applications. UHMW is also used in mining, paper and pulp processing, and in the food and beverage industries.

Overall applications for Olefins also include bearings, conveyor parts, wear surfaces, gears, sprockets, feed screws, cams, liners, guide rails, feed chutes, star wheels, drag chain wear strips, and mixing paddles and scrapers.

Availability: Many thermoplastics are available in a multitude of forms such as sheets, rods, and tubes.

Fabrication: The Gund Company can fabricate a wide range of thermoplastic components per the specifications of our customers. Please do not hesitate to call or fax us your requirements.

The Gund Company, Inc.
St. Louis, Missouri

Tel: (314) 423-5200
Fax: (314) 423-9009

Material Data Sheet

Item: Polyolefins

Typical Properties:	**Polyethylene, Hi Molecular Weight: (Average Value)**
Physical Properties	
Specific Gravity	0.940 - 0.942
Specific Volume (cu. in. per lb.)	29.8
Refractive Index	----
Tensile Strength (PSI)	2,500
Elongation (%)	5.25
Modulus of Elasticity in Tension (10^3, PSI)	1.02
Compressive Strength (PSI)	----
Flexural Strength (PSI)	----
Impact Strength (ft.-lb. per in. of notch)	No Break
Rockwell Hardness	R38
Thermal Conductivity	----
Specific Heat (cal per C° per gm)	----
Thermal Expansion (.001 per C°)	7.2
Resistance to Heat (F°, continuous)	----
Heat Distortion Temperature (F°)	163
Volume Resistivity	10
Electrical Properties	
Dielectric Strength (short time 1/8 thick)	710
Dielectric Strength (step-by-step 1/8 thick)	680
Dielectric Constant (60 cycles)	----
Dielectric Constant (10^3 cycles)	----
Dielectric Constant (10^6 cycles)	230
Dissipation (Power) Factor (60 cycles)	----
Dissipation (Power) Factor (10^3 cycles)	----
Dissipation (Power) Factor (10^6 cycles)	0.0002
Arc Resistance (Seconds)	----
Chemical Properties	
Water Aborption (24 hr., 1/8 in thick, %)	0.01
Burning Rate	Very Slow
Effect of Sunlight	----
Effect of Weak Acids	Very Resistant
Effect of Strong Acids	----
Effect of Weak Alkalies	----
Effect of Strong Alkalies	----
Effect of Organic Solvents	----
Clarity	Translucent to Opaque

All of the information, suggestions, and recommendations pertaining to the properties and uses of the products herein are based upon tests and data believed to be accurate; however, the final determination regarding the suitability of any material described herein for the use contemplated, the manner of such use, and whether the use infringes any patents is the sole responsibility of the user. There is no warranty, expressed or implied, including, without limitation warranty of merchantability or fitness for a particular purpose. Under no circumstances shall we be liable for incidental or consequential loss or damage.

Proposed material from the same vendor but with beter wear resistance.

MANUFACTURERS OF
ELECTRICAL INSULATION MATERIALS
INSULATING COMPONENTS FOR
POWER SYSTEMS EQUIPMENT

The Gund Company, Inc
St. Louis, Missouri – USA
TEL - 314.423.5200
FAX - 314.423.9009

MATERIAL DATA SHEET

Item: UHMW-PE

Key Characteristics:	Test Method	Units - English (SI)	Typical Values
Specific Gravity, 73℉	ASTM D792	--	0.94
Tensile Strength, 73℉	ASTM D638	psi	5,500
Tensile Modulus of Elasticity, 73℉	ASTM D638	psi	116,000
Flexural Strength, 73℉	ASTM D790	psi	3,600
Flexural Modulus of Elasticity, 73℉	ASTM D790	psi	116,000
Compressive Strength, 10% Deformation, 73℉	ASTM D695	psi	3,300
Compressive Modulus of Elasticity, 73℉	ASTM D695	psi	100,000
Hardness, Durometer, Shore "D" Scale, 73℉	ASTM D2240	--	68
IZOD Impact Strength, Notched, 73℉	ASTM D256 Type "A"	ft.lb./in.	No Break
Coefficient of Friction (Dry vs. Steel) Dynamic	QTM 55007	--	0.15
Heat Deflection Temperature, 264 psi	ASTM D648	℉	116
Continuous Service Temperature in Air[1], Max.	--	℉	180
Dielectric Strength, Short Term	ASTM D149	Volts/mil	n/a
Surface Resistivity	ASTM D257	Ohms/square	> 10^{15}
Flammability @ 3.1 mm, 1/8 in. [2]	UL94	--	HB
Water Absorption Immersion, 24 Hours	ASTM D570 [2]	% by weight	< 0.01
Water Absorption Immersion, Saturation	ASTM D570 [2]	% by weight	< 0.01

1 Data represents estimated maximum long-term service temperature based on practical field experience
2 Specimens: 1/8" thick x 2" diameter or square

Appendix B-Data Sheets From Different Vendors

Vendor 1- Interstate Plastic

laterial Datasheet

Quadrant EPP TIVAR® 1000 Natural Virgin UHMW-PE

Physical Properties	Metric	English	Comments
Specific Gravity	0.93 g/cc	0.0336 lb/in³	ASTM D792
Water Absorption	Max 0.01 %	Max 0.01 %	Immersion, 24hr; ASTM D570(2)
Water Absorption at Saturation	Max 0.01 %	Max 0.01 %	Immersion; ASTM D570(2)
Mechanical Properties			
Hardness, Shore D	66	66	ASTM D2240
Tensile Strength, Ultimate	40 MPa	5800 psi	ASTM D638
Elongation at Break	300 %	300 %	ASTM D638
Tensile Modulus	0.689 GPa	100 ksi	ASTM D638
Flexural Modulus	0.758 GPa	110 ksi	ASTM D790
Flexural Yield Strength	24.1 MPa	3500 psi	ASTM D790
Compressive Strength	20.7 MPa	3000 psi	10% Def., 73°F; ASTM D695
Compressive Modulus	0.552 GPa	80 ksi	ASTM D695
Shear Strength	33.1 MPa	4800 psi	ASTM D732
Coefficient of Friction	0.12	0.12	Dry vs. Steel; QTM55007
Limiting Pressure Velocity	0.0701 MPa-m/sec	2000 psi-ft/min	4:1 safety factor; QTM 55007
Izod Impact, Notched	NB	NB	ASTM D256 Type A
Electrical Properties			
Surface Resistivity per Square	Min 1e+015 ohm	Min 1e+015 ohm	ASTM D257
Dielectric Constant	2.3	2.3	(1MHz); ASTM D150
Dielectric Strength	90.6 kV/mm	2300 V/mil	Short Term; ASTM D149
Dissipation Factor	0.0005	0.0005	(1MHz); ASTM D150
Thermal Properties			
CTE, linear 68°F	216 µm/m-°C	120 µin/in-°F	(-40°F to 300°F); ASTM E831
Thermal Conductivity	0.409 W/m-K	2.84 BTU-in/hr-ft²-°F	
Melting Point	135 °C	275 °F	Crystalline, Peak; ASTM D3418
Maximum Service Temperature, Air	82.2 °C	180 °F	Long Term
Deflection Temperature at 1.8 MPa (264 psi)	46.7 °C	116 °F	ASTM D648
Flammability, UL94 (Estimated Rating)	HB	HB	1/8 inch
Qualitative Processing Properties			
Compliance - FDA	Compliant		
Machinability	3		1-10, 1=Easier to Machine
Service in Alcohols	Acceptable		
Service in Aliphatic Hydrocarbons	Acceptable		
Service in Aromatic Hydrocarbons	Unacceptable		
Service in Chlorinated Solvents	Acceptable		

http://quadrant.matweb.com/SpecificMaterialPrint.asp?bassnum=p1smp00 10/26/2009

Vendor 2- RPlastic.com

ing Engineering Plastics and Röchling Machined Plastics

RÖCHLING
Engineered Plastics

M (UHMW-PE) CHEMICAL PROPERTIES

Polystone® M Chemical Properties

Chemical Resistance	Polystone® M (UHMW-PE)		Polystone® M (UHMW-PE)
Acetaldehyde	+	Glycerine	+
Acetic acid	+	Hydrochloric acid	+
Acetone	+	Hydrogen peroxide	+
Acrylonitrile	+	Hydrogen sulphide	+
Allyl alcohol	96+	Lactic acid	+
Aluminum chloride	A+	Magnesium chloride	A+
Ammonia	A+	Mercury	+
Ammonium chloride	A+	Methanol	+
Aniline	+	Methyl ethyl ketone	+
Benzaldehyde	+	Methylene chloride	/
Benzene	/	Mineral oil	+
Benzyl alcohol	+	Motor oil	+
Bleach (Chlorine)	-	Nitric acid	+to/
Boric acid	A+	Nitobenzene	+
Butanol	+	Oleic acid	+
Butyl acetate	+	Ozone	/
Calcium chloride	+	Perchloric acid	50+
Carbon disulphide	/	Petroleum	+
Carbon tetrachloride	/M-	Phenol	+
Chlorine gas	/	Phosphoric acid	+
Chlorobenzene	/	Potassium chromate	40+
Chloroform	/M-	Potassium hydroxide	30+
Chromic acid	10+	Potassium nitrate	+
Citric acid	+	Potassium permanganate	+
Cyclohexanol	+	Pyridine	+
Cyclohexanone	+	Sea water	+
Dekalin	+	Sodium carbonate	10+
Dibutyl phthalate	+	Sodium chloride	10+
Diesel fuel	+	Sodium hydroxide	60+
Diethyl ether	+to/	Sulphuric acid	75+
Dioxane	+	Tallow	+
Ethanol	96+	Tetrahydrofurane	+M-
Ethyl acetate	+	Tetralin	+
Ethylene chloride	/	Thionyl chloride	-
Ethylene diamine	+	Toluene	/

Appendix C-New vs. Damaged Paddle

Figure 50-New vs. Damaged Paddle

Appendix D-RBT Drag-A-Flight Conveyor

Figure 51-Drag a Flight Conveyor from RBT

Appendix E-Water Jet Machining Illustration

Figure 52-Precise Cutting, Clean and Smooth Finish of Water Jet Machining

Appendix F-Drill Bit and Saw Blade Description

THINK PLASTIC DRILLING

FRACTIONAL DRILLS

PART #	CED	CEL	SHK DIA	OAL
70-502	1/8 (0.125)	1 1/2	1/8	2 3/4
70-503	9/64 (0.141)	1 3/4	9/64	2 7/8
70-506	5/32 (0.156)	1 15/16	5/32	3 1/8
70-509	11/64 (0.172)	1 3/4	11/64	3 1/4
70-510	3/16 (0.188)	2 1/8	3/16	3 1/2
70-511	13/64 (0.203)	2 7/16	13/64	3 5/8
70-512	7/32 (0.219)	2 1/2	7/32	3 3/4
70-513	15/64 (0.234)	2 5/8	15/64	3 7/8
70-514	1/4 (0.250)	2 11/16	1/4	4
70-515	17/64 (0.266)	2 7/8	17/64	4 1/8
70-516	9/32 (0.281)	2 15/16	9/32	4 1/4
70-517	19/64 (0.297)	3 1/16	19/64	4 3/8
70-520	5/16 (0.313)	1 3/4	5/16	3 1/8
70-521	21/64 (0.328)	3 5/16	21/64	4 5/8
70-522	11/32 (0.344)	3 7/16	11/32	4 3/4
70-523	23/64 (0.359)	3 1/2	23/64	4 7/8
70-524	3/8 (0.375)	2 3/4	3/8	4 3/8
70-525	25/64 (0.391)	3 3/4	25/64	5 1/8
70-526	13/32 (0.406)	3 7/8	13/32	5 1/8
70-527	27/64 (0.422)	3 15/16	27/64	5 3/8
70-528	7/16 (0.438)	2 1/2	7/16	4 3/4
70-529	29/64 (0.453)	4 3/16	29/64	5 5/8
70-530	15/32 (0.469)	4 5/16	15/32	5 3/4
70-531	31/64 (0.484)	4 3/8	31/64	5 7/8
70-532	1/2 (0.500)	2 5/8	1/2	5 1/8
70-533	33/64 (0.516)	3 1/8	1/2	6
70-534	17/32 (0.531)	3 1/8	1/2	6
70-535	35/64 (0.547)	3 1/8	1/2	6
70-536	9/16 (0.563)	3 1/8	1/2	6
70-537	37/64 (0.578)	3 1/8	1/2	6
70-538	19/32 (0.594)	3 1/8	1/2	6
70-539	39/64 (0.609)	3 1/8	1/2	6
70-540	5/8 (0.625)	3 1/8	1/2	6
70-541	41/64 (0.641)	3 1/8	1/2	6
70-542	21/32 (0.656)	3 1/8	1/2	6
70-543	43/64 (0.672)	3 1/8	1/2	6
70-544	11/16 (0.688)	3 1/8	1/2	6
70-545	45/64 (0.703)	3 1/8	1/2	6
70-546	23/32 (0.719)	3 1/8	1/2	6
70-547	47/64 (0.734)	3 1/8	1/2	6
70-548	3/4 (0.750)	3 1/8	1/2	6
70-549	49/64 (0.766)	3 1/8	1/2	6
70-550	25/32 (0.781)	3 1/8	1/2	6
70-551	51/64 (0.797)	3 1/8	1/2	6
70-552	13/16 (0.813)	3 1/8	1/2	6
70-553	53/64 (0.828)	3 1/8	1/2	6
70-554	27/32 (0.844)	3 1/8	1/2	6
70-555	55/64 (0.859)	3 1/8	1/2	6
70-556	7/8 (0.875)	3 1/8	1/2	6
70-557	57/64 (0.891)	3 1/8	1/2	6
70-558	29/32 (0.906)	3 1/8	1/2	6
70-559	59/64 (0.922)	3 1/8	1/2	6
70-560	15/16 (0.938)	3 1/8	1/2	6
70-561	61/64 (0.953)	3 1/8	1/2	6
70-562	31/32 (0.969)	3 1/8	1/2	6
70-563	63/64 (0.984)	3 1/8	1/2	6

HSS PLASTIC DRILLS

Onsrud's high-speed-steel drills are designed to produce holes in hard and soft plastic while eliminating edge chipping and chip wrapping. The point is specially ground at a 60° angle for gradual penetration into the material while eliminating cracking and chipping. The 0° rake angle on the cutting edge eliminates grabbing as the drill exits through the material producing a clean hole.

Custom sizes can be made upon request.

NO Wrapping
NO Cleaning
NO Melting
NO Surface Marring
NO Interrupted Operation

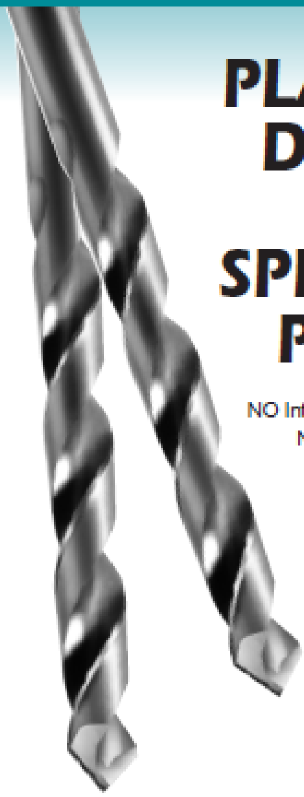
FASTER, CLEANER HOLES

THINK ONSRUD

03/05

ONSRUD CUTTER LP
800 Liberty Drive
Libertyville, IL 60048, USA
Phone 800.234.1560
Fax 847.362.5028
www.onsrud.com
www.plasticrouting.com

LMT
Leitz Metalworking Technology Group



PLASTIC DRILLS WITH SPECIAL POINT

NO Interrupted Operation
NO Surface Marring
NO Wrapping
NO Cleaning
NO Melting

FASTER CLEANER HOLES

LETTER DRILLS

PART #	CED	CEL	SHK DIA	OAL
70-600	A (0.234)	2 5/8	0.234	3 7/8
70-601	B (0.238)	2 3/4	0.238	4
70-602	C (0.242)	2 3/4	0.242	4
70-603	D (0.246)	2 3/4	0.246	4
70-604	E (0.250)	2 3/4	0.250	4
70-605	F (0.257)	2 7/8	0.257	4 1/8
70-606	G (0.261)	2 7/8	0.261	4 1/8
70-607	H (0.266)	2 7/8	0.266	4 1/8
70-608	I (0.272)	2 7/8	0.272	4 1/8
70-609	J (0.277)	2 7/8	0.277	4 1/8
70-610	K (0.281)	2 15/16	0.281	4 1/4
70-611	L (0.291)	2 15/16	0.291	4 1/4
70-612	M (0.295)	3 1/16	0.295	4 3/8
70-613	N (0.302)	3 1/16	0.302	4 3/8
70-614	O (0.316)	3 3/16	0.316	4 1/2
70-615	P (0.323)	3 5/16	0.323	4 5/8
70-616	Q (0.332)	3 7/16	0.332	4 3/4
70-617	R (0.339)	3 7/16	0.339	4 3/4
70-618	S (0.348)	3 1/2	0.348	4 7/8
70-619	T (0.358)	3 1/2	0.358	4 7/8
70-620	U (0.368)	3 5/8	0.368	5
70-621	V (0.377)	3 5/8	0.377	5
70-622	W (0.386)	3 3/4	0.386	5 1/8
70-623	X (0.397)	3 3/4	0.397	5 1/8
70-624	Y (0.404)	3 7/8	0.404	5 1/4
70-625	Z (0.413)	3 15/16	0.413	5 1/4

WIRE DRILLS

PART #	CED	CEL	SHK DIA	OAL
70-630	1 (0.228)	2 5/8	0.228	3 7/8
70-631	2 (0.221)	2 5/8	0.221	3 7/8
70-632	3 (0.213)	2 1/2	0.213	3 3/4
70-633	4 (0.209)	2 1/2	0.209	3 3/4
70-634	5 (0.206)	2 1/2	0.206	3 3/4
70-635	6 (0.204)	2 1/2	0.204	3 3/4
70-636	7 (0.201)	2 7/16	0.201	3 5/8
70-637	8 (0.199)	2 7/16	0.199	3 5/8
70-638	9 (0.196)	2 7/16	0.196	3 5/8
70-639	10 (0.194)	2 7/16	0.194	3 5/8
70-640	11 (0.191)	2 5/16	0.191	3 1/2
70-641	12 (0.189)	2 5/16	0.189	3 1/2
70-642	13 (0.185)	2 5/16	0.185	3 1/2
70-643	14 (0.182)	2 3/16	0.182	3 3/8
70-644	15 (0.180)	2 3/16	0.180	3 3/8
70-645	16 (0.177)	2 3/16	0.177	3 3/8
70-646	17 (0.173)	2 3/16	0.173	3 3/8
70-647	18 (0.170)	2 1/8	0.170	3 1/4
70-648	19 (0.166)	2 1/8	0.166	3 1/4
70-649	20 (0.161)	2 1/8	0.161	3 1/4
70-650	21 (0.159)	2 1/8	0.159	3 1/4
70-651	22 (0.157)	2	0.157	3 1/8
70-652	23 (0.154)	2	0.154	3 1/8
70-653	24 (0.152)	2	0.152	3 1/8
70-654	25 (0.150)	1 7/8	0.150	3
70-655	26 (0.147)	1 7/8	0.147	3
70-656	27 (0.144)	1 7/8	0.144	3
70-657	28 (0.141)	1 3/4	0.141	2 7/8
70-658	29 (0.136)	1 3/4	0.136	2 7/8
70-659	30 (0.129)	1 5/8	0.129	2 3/4
70-660	31 (0.120)	1 5/8	0.120	2 3/4

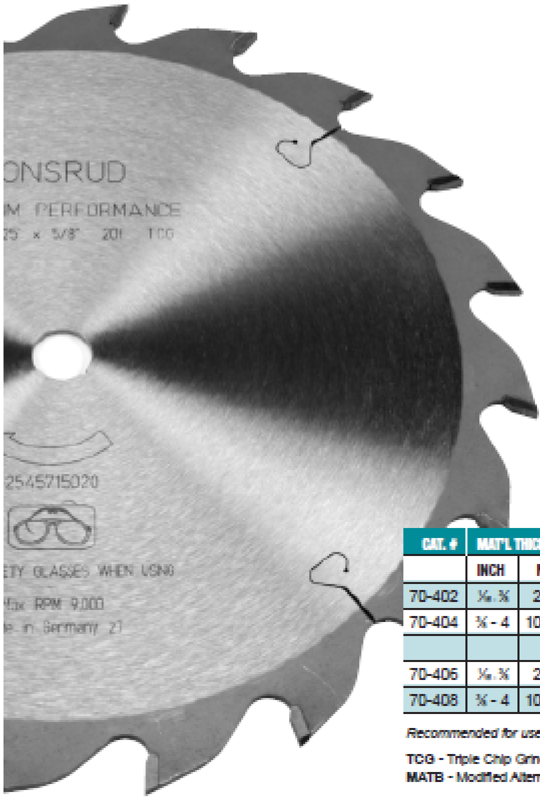
METRIC DRILLS

PART #	CED	CEL	SHK DIA	OAL
70-714	3.00 (0.118)	41	3.00	70
70-715	3.50 (0.138)	44	3.50	73
70-716	4.00 (0.157)	54	4.00	83
70-717	4.50 (0.177)	56	4.50	86
70-718	5.00 (0.197)	62	5.00	92
70-719	5.50 (0.217)	64	5.50	95
70-720	6.00 (0.236)	70	6.00	102
70-721	6.50 (0.256)	73	6.50	105
70-722	7.00 (0.276)	73	7.00	105
70-723	7.50 (0.295)	78	7.50	111
70-724	8.00 (0.315)	81	8.00	114
70-725	8.50 (0.335)	87	8.50	121
70-726	9.00 (0.354)	89	9.00	124
70-727	9.50 (0.374)	92	9.50	127
70-728	10.00 (0.394)	95	10.00	130
70-729	10.50 (0.413)	98	10.50	133
70-730	11.00 (0.433)	103	11.00	140
70-731	11.50 (0.453)	106	11.50	143
70-732	12.00 (0.472)	111	12.00	149
70-733	12.50 (0.492)	114	12.50	152
70-734	13.00 (0.512)	114	13.00	152
70-735	13.50 (0.531)	122	13.50	168
70-736	14.00 (0.551)	122	14.00	168
70-737	14.50 (0.571)	122	14.50	168
70-738	15.00 (0.591)	132	15.00	181
70-739	15.50 (0.610)	132	15.50	181
70-740	16.00 (0.630)	132	16.00	181
70-741	16.50 (0.650)	132	16.50	181
70-742	17.00 (0.669)	143	17.00	194
70-743	17.50 (0.689)	143	17.50	194

the ONSRUD advantage

PLASTIC SAWING

70-400 SERIES



Saw Blades with Unique Geometry for Cutting Plastic Materials

Special-application blades for phenolic, hard and soft plastic materials.

Premium performance design results in cool, clean cutting without chipping or melting. Blade design is optimized for either thick or thin material.

PRODUCT OFFERING

CAT. #	MAT'L THICKNESS		DIAMETER				KERF		PLATE		
	INCH	MM	INCH	MM	TEETH	GRIND	INCH	MM	INCH	MM	ARBOR
70-402	1/16 - 3/8	2-10	10"	250	60	MATB	0.126	3.2	0.087	2.2	5/8
70-404	3/8 - 4	10-100	10"	250	20	TCG	0.126	3.2	0.087	2.2	5/8
70-406	1/16 - 3/8	2-10	12"	300	72	MATB	0.126	3.2	0.087	2.2	1
70-408	3/8 - 4	10-100	12"	300	22	TCG	0.126	3.2	0.087	2.2	1

Recommended for use on table, miter and panel saws

TCG - Triple Chip Grind
MATB - Modified Alternate Top Bevel

Other features of the Onsrud product offering include:

Laser Cut Bodies - true running blade for accurate cutting

Laser Cut Expansion Slots - reduces harmonic vibration for low noise and clean cuts

Laser Cut and Polished Bore - true centering of the blade to the arbor for optimal performance

the ONSRUD advantage
more than just cutting tools

ONSRUD CUTTER LP
800 Liberty Drive • Libertyville, IL60048, USA
Phone 800.234.1560 • Fax 847.362.5028
www.onsrud.com•www.plasticrouting.com
LMT Leitz Metalworking Technology Group

Appendix G-Safety Manual

Safety Information Manual

IMPORTANT!
FAILURE TO FOLLOW THESE SAFETY INSTRUCTIONS CAN RESULT IN SEVERE INJURY OF DEATH

GENERAL:

ONLY TRAINED AND AUTHORIZED PERSONEL MAY OPERATE THE MACHINE.

PROPER EYE PROTECTION MUST BE WORN BY OPERATOR AND ALL OBSERVERS

1. **No Smoking** is permitted!
2. **Clear Working Area:** The area around loading and unloading points shall be kept clear of obstructions which could endanger personnel.
3. **Machine Service**: Service machine with only authorized maintenance personnel.
4. **Eye Protection**: Approved eye protection must be worn at all times in the shop area.
5. **Wear Proper Apparel**: Appropriate clothing is required while operating the machine. It is prohibited to wear shorts and open toed shows.

   Wear protective hair covering to contain long hair to prevent becoming entangled in the machines.
   Do not wear gloves; do not hold rag while operating machinery. They can be easily caught in the machines that are in motion, pulling the operator into the equipment.
6. **Keep Hand Clear of Moving Parts**: Hands are to be kept clear of moving parts while equipment is in motion. Machines must be completely stopped before handling moving parts or the work piece.
7. **Keep Guards in Place**: The safety guards are to be kept in place at all times, unless the shop supervisor gives you permission to remove them.
8. **Prevent Slippage**: Spill fluid or cutting material found around work area must be clean immediately to prevent slipping and injury.
9. **Care of Hazardous Material**: Only approved chemicals will be used. All hazardous materials and their disposal must meet OSHA requirements.

   Contact the Environmental Safety Office for disposal of all chemicals.
10. **Turn Power Off**: Never leave tools running unattended. Turn power off.
11. **Turn the Motor Switch Off** and unplug from the power source when not in operation
12. **Reduce the Risk of Unintentional Starting**. Make sure switch is in off position before plugging in.
13. **Never stand on tools.**

14. **Plug in the Tool:** Using a power source with voltage less than the nameplate rating is harmful to the motor.
15. **Extension Cord:** Make sure your extension cord is in good condition. When using an extension cord, be sure to use one heavy enough to carry the current your product will draw. An under sized cord will cause a drop in line voltage resulting in loss of power and overheating.
16. **Manager must be notified immediately if broken tools are found or if the machine is not operating correctly.**

Conveyor Safety

SAFTEY INFORMATION

- **INSTALLATION**

1. **Interfacing of Equipment.** When two or more pieces of equipment are interfaced, special attention shall be given to the interfaced area to insure the presence of adequate guarding and safety devices.
2. **Guarded by Location or Position.** Where necessary for the protection of employees from hazards, all exposed moving machinery parts that present a hazard to employees at their work station shall be mechanically or electrically guarded, or guarded by location or position.

   When a conveyor passes over a walkway, or work station, it is consider guarded solely by location or position if all moving parts are at least 8 ft. (2.44 m) above the floor or walking surface or are otherwise located so that the employee cannot inadvertently come in contact with hazardous moving parts.

- **OPERATION**

1. **Do Not Ride, Step, Sit or Climb on Conveyor.**
2. A conveyor shall be used to transport only material it is capable of handling safely.
3. **The work piece must be securely** clamped before turning machine ON
4. Don't perform service on conveyor until motor disconnect is Locked Out!
5. Inspections and preventive and corrective maintenance programs shall be conducted to insure that all safety features and machine parts are functioning properly.
6. Keep clothing, fingers, hair, and other parts of the body away from conveyor!
7. Don't load conveyor outside of the design limits.
8. Don't remove or alter conveyor guards or safety divides.
9. Know location and function of stop/start push button.
10. Keep all stopping/starting control devices free from obstructions.

11. Ensure all personnel be clear of conveyor before starting.
12. Report all unsafe practices and machine parts to your manager.

- **MAINTENANCE**

1. Maintenance, such as lubrication and adjustments, shall be performed only by qualified and trained personnel.
2. It is important that a maintenance program be established to insure that all conveyor components are maintained in a condition which does not constitute a hazard to personnel.
3. When a conveyor is stopped for maintenance purposes, starting devices or powered accessories shall be locked or tagged out in accordance with a formalized procedure, designed to protect all person or groups involved with the conveyor against an unexpected start.
4. DO NOT lubricate conveyors while they are in motion. Only trained personnel who are aware of the hazard of the conveyor in motion shall be allowed to lubricate.
5. Maintain all guards and safety devices IN POSITION and IN SAFE REPAIR
6. Maintain all warning signs in a legible condition and obey all warnings.

Saw Blade Safety

SAFETY INFORMATION

- **INSTALLATION**

A new saw blade and blade guard are not in the installed condition. Assemble as follows:

CAUTION: Always unplug the tool before assembly.

1. **Installing a new saw blade:** Uninstall the circular saw blade by loosening the screws holding the blade. Always make sure that while dismantling, your arms or body is not directly in front of the saw.

Assemble the new blade making sure that the blade's teeth are pointing down at the tip of the roller table and aligned in the direction of cutting.

CAUTION: Avoid having dust or dirt on the flange, as this could provoke slippage of the blade.

Securely adjust the new saw blade to the assembly with a wrench, using a glove if necessary

Installing blade guard

CAUTION: Before installing the blade guard, adjust the depth of cut to its maximum elevation. Insert the spreader between the blade guard mounting portion (stay) and the pressure plate.

Tighten the hex bolts (A) with the offset wrench. The spreader installing location is factory-adjusted so that the blade and spreader will be in a straight line. However, if they are not in a straight line, loosen the hex bolts (B) and adjust the blade guard mounting portion (stay) so that the spreader is aligned directly behind the blade. Then tighten the hex bolts (B) to secure the stay.

CAUTION: Always grasp the striped portion of the offset wrench when tightening the hex bolts. If you tighten the hex bolts while grasping the offset wrench further than the striped portion, the hex bolts may be damaged and/or an injury to your hand may result. If the blade and spreader are not aligned properly, a dangerous pinching condition may result during operation.

Make sure they are properly aligned. You could suffer serious personal injury while using the tool without a properly aligned spreader.

NEVER make any adjustments while tool is running. Disconnect the tool before making any adjustments.

There must be a clearance of about 4 - 5 mm (5/32” - 13/64”) between the spreader and the blade teeth. Adjust the spreader accordingly and tighten the hex bolts (A) securely. Attach the table insert on the table, then check to see that the blade guard works smoothly before cutting.

2. **Adjusting depth of cut** The depth of cut may be adjusted by turning the handle. Turn the handle clockwise to raise the blade or counterclockwise to lower it.
   NOTE: Use a shallow depth setting when cutting thin materials in order to obtain a cleaner cut.
3. **Adjusting bevel angle** Loosen the lock lever counterclockwise and turn the hand wheel until the desired angle (0° - 45°) is obtained. The bevel angle is indicated by the arrow pointer. After obtaining the desired angle, tighten the lock lever clockwise to secure the adjustment.
   CAUTION: After adjusting the bevel, be sure to tighten the lock lever securely.
4. **Adjusting positive stops** The tool is equipped with positive stops at 90° and 45° to the table surface. To check and adjust the positive stops, proceed as follows: Move the hand wheel as far as possible by turning it. Place a triangular rule on the table and check to see if the blade is at 90° or 45° to the table surface. If the blade is at an angle shown in Fig. A, turn the adjusting screws clockwise; if it is at an angle shown in Fig. B, turn the adjusting screws counterclockwise to adjust the positive stops.

5. **Switch action** This tool is equipped with a special type of switch to prevent unintentional starting. To start the tool, first depress the switch lever. While keeping it depressed, pull its lower portion toward you. To stop the tool, press the lower portion of the switch lever
   CAUTION: Always use “work helpers” such as push sticks and push blocks when there is a danger that your hands or fingers will come close to the blade.
   Always hold the work piece firmly with the table and the rip fence or miter gauge. Do not bend or twist it while feeding. If the work piece is bent or twisted, dangerous kickbacks may occur.

NEVER withdraw the work piece while the blade is running. If you must withdraw the work piece before completing a cut, first switch the tool off while holding the work piece firmly. Wait until the blade has come to a complete stop before withdrawing the work piece. Failure to do so may cause dangerous kickbacks.

NEVER remove cut-off material while the blade is running.

NEVER place your hands or fingers in the path of the saw blade. Be especially careful with bevel cuts.

Always secure the rip fence firmly, or dangerous kickbacks may occur.

Always use "work helpers" such as push sticks and push blocks when cutting small or narrow work pieces, or when the dado head is hidden from view while cutting.

6. **Work helpers** Push sticks, push blocks or auxiliary fence are types of "work helpers". Use them to make safe, sure cuts without the need for the operator to contact the blade with any part of the body.

- **OPERATION**

CAUTION:

1. NEVER remove cut-off material while the blade is running
2. NEVER place your hands or fingers in the path of the saw blade. Be especially careful with bevel cuts
3. NEVER stand or permit anyone else to stand in line with the path of the saw blade.
4. **Read the Manual**: Read all warning labels and the owner's manual before operating the saw.
5. **Direction of Feed:** Feed work into a blade or cutter against the direction of rotation of the blade or cutter
6. **Check for damaged Blade** before operation. Ask a technician to replace cracked or damaged blade immediately.
7. **Watch for Vibration**: that could indicate poor installation.
8. **Use blade guards**
9. **Minimize the blade height.** Ensure the height is ¼" to ½" below the gullet.

10. **Do not wear gloves** Gloves cause a loss to your sense of touch as well as a possible loss of gripping power.
11. **Lower Blade When Work is Done**: After finishing your work the saw blade should be lowered below the table
12. Use a sharp, clean blade.
13. **Never** 'freehand' a cut
14. **Stop Button**: Ensure that the stop button is easily accessible.
15. Turn off the saw before removing small cut off pieces
16. Use eye and ear protection
17. Do not reach over the saw blade when it is running. This puts you off balance and you could slip into the blade

- **MAINTENANCE**

  CAUTION: Always be sure that the tool is switched off and unplugged before attempting to perform inspection or maintenance.

1. **Cleaning**: Clean out chips from time to time.
2. **Lubrication:** Keep the saw in running condition at all time to assure maximum service life
3. **Lubrication places:**

   -Threaded shaft to elevate the blade

   -Elevation guide shafts on motor

Electric Drill Safety

SAFETY INFORMATION

- **INSTALLATION**

1. Ensure that the drill machine has a start/stop button within easy reach of the operator.

Further details will be added as the machine is completed.

- **OPERATION**

CAUTION: THE MACHINE IS RUNNING AUTOMATICALLY WHEN SWITCH TURNED ON

1. Prior to or before operating this machinery operator must ensure that he/she understood the owner's operator's manual.

   Learn the machine's applications and limitations, as well as the specific potential hazards peculiar to this machine. Follow available operating instructions and safety rules carefully.
2. Do not allow hands to come in contact with the drills bit while it is in motion
3. The work piece must be securely clamped
4. Use a vacuum, brush or rake to remove cuttings
5. Remove burrs and chips from a drilled hole
6. Keep drill bits clean and sharp. Dull drills are a common cause of breakage.
7. Keep floor around the drill machine free of oil and grease.
8. Keep guards in place and in good working order
9. Do not remove cuttings by hand. Wait until the machine has stopped running to clear cuttings with a vacuum, brush or rake
10. Do not leave machines running unattended. Turn power off
11. Be sure the power is shut off before changing drill bits
12. Be sure drill bit or cutting tool is securely locked in the chuck

Inform the technician if the tool seems to be malfunctioning or is damaged.

Appendix H-Paddle Maker's User Manual

Paddle Maker's User Manual

In the following document the steps necessary for the user to effectively operate the Paddle Maker Machine are named and explained.

Figure 53-Paddle Maker Prototype

Be advised that using this machine may cause harm if safety precautions and instructions in this manual are not followed. Please refer to the Safety Manual also attached in this report for further details. Also note that for an accurate cut, given the nature of UHMWPE that this machinery should be inside a closed facility, kept at room temperature, to avoid deflection and dust in the work piece. In between paddles have an employee dust the work piece with a pressure air hose. It is of great importance to know beforehand, the direction and purpose of each axes. For this refer to the table below:

Table 8-Axis Function and Direction

Axis	Function	+ Direction
X	drill horizontal movement	to the rigth
Y	Saw horizontal movement	to the rigth
Z	drill vertical movement	up
A	sheet mover	clockwise

Operation Routine

1. Do not Turn Power On.

2. Check that the sheet of UHMWPE is in the starting position by the end of the roller table, being pressed by the rubber wheels of the table mover mechanism.

3. Assure that the screw connections between the computer and the driver in the hardware box are not loose.

4. Verify that the saw's blade is in good condition and well adjusted.

5. Check that the drill bit in the drilling assembly is operable.

6. Connect both the machine and computer plugs to the outlets.

7. Turn on the computer and open Mach 3 Loader.

8. Load the G-code attached in section 7.1.2 of this report.

9. Make sure that the four axes; X, Y, Z, A are in their respective home positions.

   NOTE: If axes are not at home position then follow the section: Moving the axis to home position below.

10. Turn the saw and drill SWITCHES ON.

11. On The Monitor click **Start Cycle** on Mach 3.

12. Carefully <u>supervised that the machine is functioning adequately</u>, and that the final product (paddle) quality is good.

ATTENTION: If needed, STOP the cycle using the ESC button on the keyboard, or STOP icon in the Mach3 interface, or by pressing the EMERGENCY BUTTON in the electronic box at the right side of the machine.

13. When there is not enough material left to do one more paddle, the machine should be stopped and a new sheet of material will be replaced

14. Repeat steps 1-13.

Moving the axis to home position

If moving an axis to his home position is required then the following steps are to be followed.

- Go to **MDI** tab in the Mach3 interface
- In the input line write: G0 x0 y0 z0 a0, all axis should move to their initials positions
- If they are not, then you need to input G0 followed by the axis and the distance wished to be moved; until the zero initial position is reached namely the first hole.
- Then go to the R**eference All Home** section, and click on the axis you just moved to the desired initial position.
- You have just set your starting point for that axis. Same process can be repeated for all other axes.
- Notice that when using this procedure, the system of coordinate being used is absolute.

Example: if you need to move the x axis 2 inches to the right, then input: G0 X2, supposing that the position you are moving in from is the zero position. Let's say that the actual position shown in the Mach3 CNC Controller under this axis is not zero but x40, and you want to move to the

right 2 inches then you would need to input: G0 X42. Similarly if moving the z axis 3 inches down, from the zero position, then inputting: G0 Z-3 would accomplish that.

For further details on using G-code and M-codes click on the bottoms found in left hand corner of the Mach3 interface.

Appendix I-Linear Stage Specifications

SERVO SYSTEMS CO.

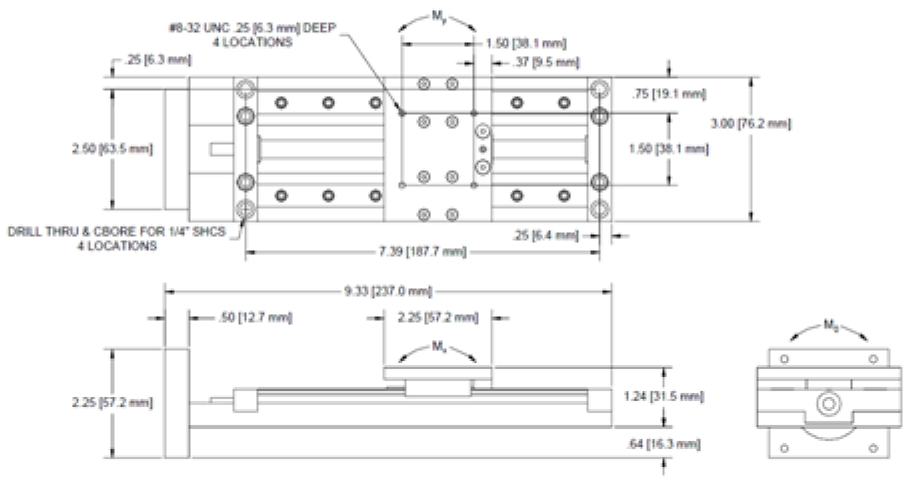
Low Profile Series Miniature Linear Stages

Model: MLPS-4-10

Description: 4 inch travel linear stage with anti-backlash lead-screw assembly, profiled linear rails, and two (one per rail) linear bearings

Motor Mount: Standard NEMA 23

Dimensions:



Specifications:

Unit Weight	**2.2 lb.**	**Linear Speed**	15 in./sec.
Moving Mass	0.372 lb.	**Leadscrew Efficiency**	81%
Travel Length	4.60 in.	**Bidirectional Repeatability**	0.0005 in.
Screw Inertia	7.808E-06 lb.-in.-sec.^{2}	**Pricing Information**	**MLPS-4-10***
Axial Moment (Mo)	90.26 in.-lb.	**Optional Accessories**	**MLPS-MFT*** Mounting Foot **MLPS-xLS*** Dual Position Limit / Home Sensors **LPS-MCH*** Manual Crank Handle **LPS-MSH*** Motor Shaft Crank Handle - fits 1/4" rear motor shaft
Perpendicular Moments (Mx & My)	48.60 in.-lb.		
Maximum Dynamic Load	10 lb.		
Payload	9.628 lb.		
Drag Torque	3 oz.-in.		
Standard Lead	0.5 in./rev.		

Notes: Stock screw pitches come in 1 in., .5 in., .25 in., and .2 in.; other screw pitches available upon request
*Contact Servo Systems Co. via phone or e-mail for pricing information

SERVO SYSTEMS Co. Servo Systems Co. • 115 Main Road • P.O. Box 97 • Montville, NJ, 07045-0097
(973) 335-1007 • Toll Free: (800) 922-1103 • Fax: (973) 335-1661 • www.servosystems.com

Appendix J-Torques Calculation

1 of 2

"Finding necessary torque for z axis motor"

z, x, y

thread depth (T.D) =

lead (l) or thread pitch (p) = 0.25" = 0.25 (0.0254) m = 0.00635 m

Power screw diameter (d_s) = 0.375 (measured)

$$d_m = d_s - \frac{l}{2} = 0.375 - \frac{0.25}{2} = 0.25''$$

e → efficiency

LINEAR STAGE

$F = W = 10\ lb_f$

$\sec\alpha = 1/\cos(29/2) = 1.033$

where $2\alpha = 29°$ is most widely used angle.

thus $\alpha = 14.5°$

Table 8.5/415 → $f = 0.25$ } worst case scenario
Table 8.6/415 → $f_c = 0.17$

d_c (mean collar diameter) = 0.25 + 0.25/2 = 0.375 "(measured)

$$T_{TOTAL} = T_R + T_c$$

a) $$T_{TOTAL} = \frac{F \cdot d_m}{2}\left(\frac{l + \pi f\, d_m \cdot \sec\alpha}{\pi d_m - f \cdot l \cdot \sec\alpha}\right) + \frac{F \cdot f_c \cdot d_c}{2} \qquad \text{(I)}$$

$$T_T = \frac{(10\ lb_f)\, 0.25}{2}\left(\frac{0.25 + \pi(0.25)(0.25)(1.033)}{\pi(0.25) - (0.25)(0.25)(1.033)}\right) + \frac{(10)(0.17)(0.375)}{2}$$

$$T_T = 1.25\left(\frac{0.453}{0.72084}\right) + 0.32 = 1.106\ lb_f \cdot in = \boxed{17.7\ \text{ounces} \cdot in}$$

feed rate obtained from Machinist toolbox for 1/4 HP

$$n = 5.25\ \frac{in}{min}\left(\frac{1\ rev}{0.25\ in}\right) = 21\ rpm \quad ; \quad e = \frac{F \cdot l}{2\pi T_R} = \frac{10 \cdot 0.25}{2 \cdot \pi (1.106)} = 0.36 = 36\%$$

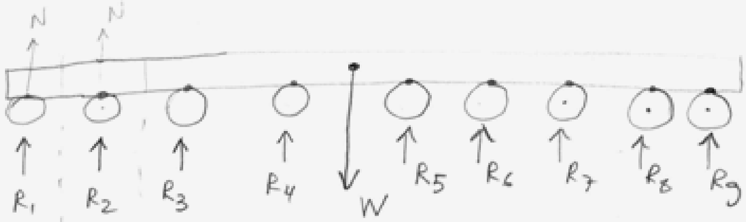
↳ lead.

b) $$H.P = \frac{T_T \cdot n(RPM)}{63025} = \frac{(1.106\ lbf \cdot in)(21\ rpm)}{63025} = 0.00037\ HP.$$

c) Velocity of drill assembly $(V_D) = n \cdot l = 21 \cdot 0.25 = 5.25$

2 of 2

"Finding necessary torque for roller Table Motor"



8" = biggest distance a roller it's holding (covering)

thus $W_s = m \cdot g = \rho \cdot V \cdot g$

$$= \frac{0.94}{1000} g \times \frac{(10^6)}{m^3} (37.25 \times 0.5 \times 8) in^3 \frac{(0.0254)^3 \ m^3}{in^3} \cdot 9.81 \frac{m}{s^2}$$

$$W_s = 22.5156 \ kg \ m/s^2 = 22.5156 \ N$$

$$T = (W_s)(r_{roller})(\mu_s) \quad \text{and} \quad \mu_s = \mu_{POLYETHELENE} + \mu_{BRGNS}$$

$$T = (22.5156 N)(1.6'' \times 0.0254 \ m)(0.2 + 0.05 \ m) = \boxed{0.23 \ N \cdot m} \approx 32.7 \text{ ounces} \cdot in$$

$\mu_{POLYETHELENE} \simeq 0.2$ from Literature survey.

$$\rho = 0.94 \ g/cm^3 = \frac{0.94}{1000} \frac{Kg}{(10^{-2})^3 m^3} = \frac{0.94 \times 10^6}{1000} Kg/m^3$$

$\mu_{BRGNS} \approx 0.05$ assumed; after reviewing Literature survey.

$$H. = \frac{T(2\pi)n}{60} = \frac{(0.23)(2\pi \cdot 1200)}{60} = 28.9 \ W = 0.039 \ H.P$$

Appendix K-Deflection Analysis of Linear Shaft

The following data was the input parameters and the corresponding results obtained from Beam 2D

BEAM LENGTH = 40.0 in MATERIAL PROPERTIES Steel AISI 4140 N: Modulus of elasticity = 29000000.0 lb/in² Stress limit = 95000.0 lb/in² CROSS-SECTION PROPERTIES Moment of inertia = 0.003067962 in^4 Top height = 0.25 in Bottom height = 0.25 in Area = 0.1963495 in² EXTERNAL CONCENTRATED FORCES 10.0 lb at 20.0 in SUPPORT REACTIONS *** Fixed at 0.0 in Reaction Force =-5.0 lb Reaction Moment =-50.0 lb-in Fixed at 40.0 in Reaction Force =-5.0 lb Reaction Moment = 50.0 lb-in MAXIMUM DEFLECTION *** 0.03746543 in at 20.0 in No Limit specified	MAXIMUM BENDING MOMENT *** -50.0 lb-in at 0.0 in -50.0 lb-in at 40.0 in 50.0 lb-in at 20.0 in MAXIMUM SHEAR FORCE *** 5.0 lb from 0.0 in to 20.0 in -5.0 lb from 20.0 in to 40.0 in MAXIMUM STRESS *** Tensile = 4074.366 lb/in² No Limit specified Compressive = 4074.366 lb/in² No Limit specified Shear (Avg) = 25.4648 lb/in² No Limit specified ANALYSIS AT SPECIFIED LOCATIONS *** Location = 20.0 in Deflection = 0.03746543 in Slope = 0.00000000000000008 deg Moment = 50.0 lb-in Shear force = 5.0 lb Tensile = 4074.366 lb/in² Compressive = 4074.366 lb/in² Shear stress = 25.4648 lb/in²

Appendix L-Drill Motor Options

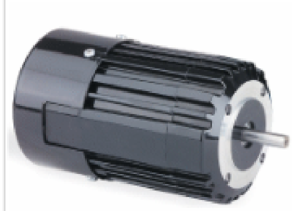
Company: Bodine Electric Company

BODINE ELECTRIC COMPANY®

34R Series AC Induction Motor

Model 0295 Specifications

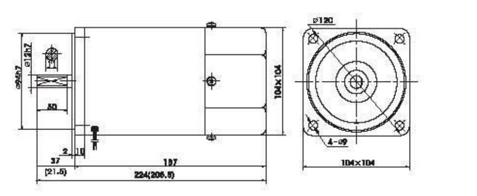
Model Number	0295
Category	Three Phase, Non-Synchronous
Speed (rpm)	1700
Rated Torque (oz-in)	119
Motor HP	1/5
Voltage	230
Hz	60
Phases	3
Amps	1.2
Radial Load (lbs)	50
Length XH (inch)	6.69
Weight (lbs)	9
Connection Diagram	074 10102
Capacitor Part Number	This model does not require a capacitor.
Product Type	34R6BFPP



MODELS IN THIS SERIES
- 0290
- 0291
- 0293
- 0294
- 0295
- 0296
- 0299
- N0297

Company: Sinotech

140 Watt 100mm AC Gear motors



Characteristics of Motors Used In Gearmotors

Model		Output	Volt	Freq	Poles	Duty	Rated			Start torq	Capacitance
Motor	Motor with gear shaft	W	V	Hz	P		Spd rpm	Curr A	Torq N.m	N.m	μF/VAC
6IK140A-AF induction motor	6IK140GU-AF gear motor gear motor	140	1ph110	50	4	CONT	1350	2.00	0.99	0.90	30.0/250
6IK140A-CF induction motor	6IK140GU-CF gear motor gear motor	140	1ph220	50	4	CONT	1350	1.13	0.99	0.90	10.0/450
6IK140A-SF induction motor	6IK140GU-SF gear motor gear motor	140	3ph220	50	4	CONT	1350	0.95	0.99	3.50	/
6IK140A-S_3F induction motor	6IK140GU-S_3F gear motor gear motor	140	3ph380	50	4	CONT	1350	0.55	0.99	3.50	/
6IK140A-DF induction motor		140	1ph220	50	2	CONT	2800	0.88	0.45	0.44	10.0/450
6IK140A-TF induction motor		140	3ph220	50	2	CONT	2800	1.25	0.48	3.33	/
6IK140A-T_3F induction motor		140	3ph380	50	2	CONT	2800	0.42	0.48	3.33	/

The required capacitor value will vary depending on operating voltage. A correct capacitor is required to match the applied voltage.

General Motor Characteristics

Insulation Resistance: 100MΩ at 500V between motor winding and shell

Insulation Voltage:1500V 50/60Hz @1min between motor winding and shell

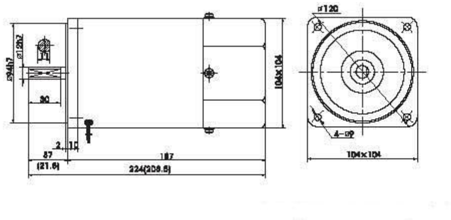
Temperature Rise: Max 80°C

Insulation Class: Class B (130°C)

Operating Temperature: -10ºC to +40ºC (Three phase -10ºC to +50ºC)

Humidity: 85% max.

Adjustable Speed Motors- Heavy Duty   (with fan)
140 Watt 100mm



The value in the ( ) is the value for the small gear shaft motor

Characteristics of Motors Used In Gearmotors

Model		Output	Volt	Freq	Poles	Duty	Speed	Allowable Torque		Start Torq	Capacitance
Motor	Motor with gear shaft							1200r	90r		
		W	V	Hz	P		rpm	N.m	N.m	N.m	μF/VAC
6IK140RA-AF adjustable speed motor	6IK140 RGU-AF adjustable speed motor w/gear shaft	140	1ph110	50	4	CONT	90~1350	0.85	0.45	0.62	30.0/250
5IK140RA-CF adjustable speed motor	6IK140 RGU-CF adjustable speed motor w/gear shaft	140	1ph220	50	4	CONT	90~1350	0.85	0.45	0.68	10.0/450

The required capacitor value will vary depending on operating voltage. A correct capacitor is required to match the applied voltage.

General Motor Characteristics

Insulation Resistance: 100MΩ at 500V between motor winding and shell

Insulation Voltage:1500V 50/60Hz @1min between motor winding and shell

Temperature Rise: Max 80°C

Insulation Class: Class B (130°C)

Operating Temperature: -10°C to +40°C (Three phase -10°C to +50°C)

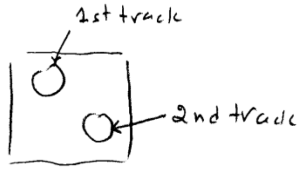
Humidity: 85% max.

Appendix M- Material Lab Notes

Tribometer test

Parameters:

time 50 min
distance 300 m
Dia track 6 mm
Ball Al_2O_3 ceramic
Load 10 N



Old Sample 1st test

Initial weight: 3.80181 g

Surface ruffness: 0.941, 1.375, 1.071, 1.404, 1.121, 1.105, 1.457 Avg: 1.2105

Time	Weight (after test)	Avg CoF	Weight Loss (change)
1st track 50 min	3.80171 g	0.162	(−) 0.00010 g
2nd track 50 min	3.80167 g	0.177	(−) 0.00014

(−) Loss
(+) gain

Orange Sample 2nd test

Initial weight 4.24297 g

Surface ruffness: 0.656, 0.417, 0.478, 0.303, 0.701. Avg: 0.511

	Time	Weight (after test)	Avg COF	Weight Loss (change)
1st Track	50 min	4.24285 g	0.255	(−) 0.00012
2nd Track	50 min	4.24303 g	0.217	(+) 0.00006

new sample 3rd test

Initial Weight: 3.46306 g

surface ruffness: 1.241, 0.516, 1.094, 1.078, 0.663, 0.941, 1.375 Avg: 0.986

	Time	Weight	Avg COF	Weight Loss
1st Track	50 min	3.462959	0.243	(−) 0.00011
2nd Track	50 min	3.46293	0.132	(−) 0.00013

AMRI Lab

OMM test → to measure diff in surface

MX410 Olympus

2000 mag 100x2x10

New sample

1st Track	groove	Top surface	Diff of
	0	16.5	16.5
	0	16	16
	0	16	16
	0	15	15
			16 Avg
2nd Track	94	6	12
	95	9	14
	98	13	15
	93	6	13
			13 Avg

From
94 to ∅ → 6
∅ to 6 → 6 +
12

Old sample

	groove surface	Top surface	Diff of
1st track	0	19	19
	0	20.5	20.5
	0	17.5	17.5
	0	16	15.5
			18 Avg
2nd Track	83	4	21
	15 85	4	19
	14 86	6	20
	14 86	7	21
			20 Avg

83 to ∅ → 17
∅ to 4 → 4
21

Orange sample

44	11	33
72	90	18
74	95	21
		24 Avg

Appendix N-Material Testing Data Samples

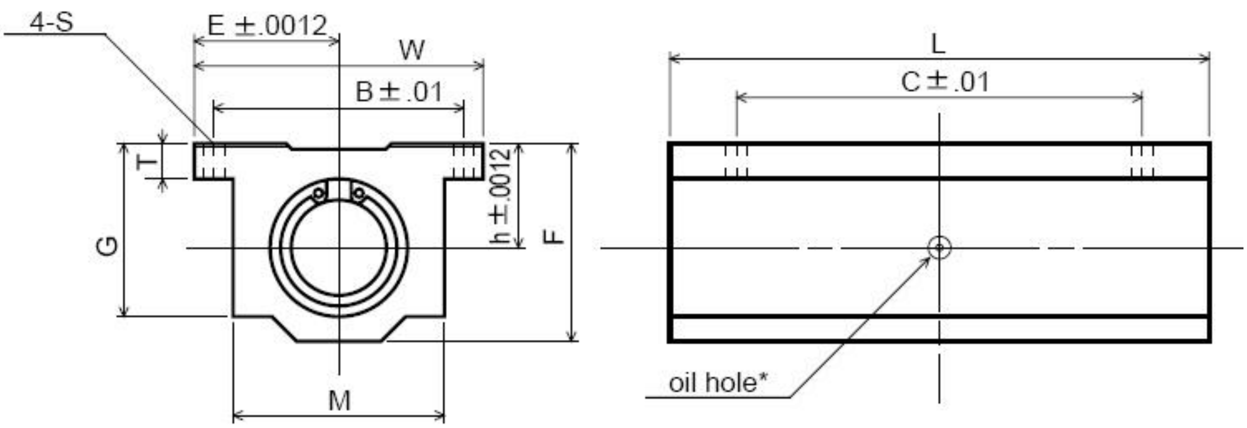
Time(min)	Distance(meters)	Coefficient of Friction	LVDT(mm)
0.0091000	0.085722	0.137471362	0.586952367
0.0098833	0.093101	0.133930433	0.590283882
0.0109333	0.102992	0.14455322	0.591192477
0.0117167	0.110371	0.141428871	0.594221127
0.0125000	0.11775	0.1449698	0.596038317
0.0135333	0.127484	0.141012291	0.599369831
0.0143167	0.134863	0.14351177	0.599369831
0.0153500	0.144597	0.138929391	0.598461237
0.0161333	0.151976	0.147469279	0.598461237
0.0169167	0.159355	0.152259948	0.599975561
0.0179667	0.169246	0.149760468	0.599975561
0.0187500	0.176625	0.137887942	0.598764102
0.0195167	0.183847	0.14392835	0.599066966
0.0205667	0.193738	0.157467196	0.601489886
0.0216000	0.203472	0.156634036	0.602095616
0.0223833	0.210851	0.157467196	0.599975561
0.0231667	0.21823	0.149552178	0.599369831
0.0242167	0.228121	0.157467196	0.600278426
0.0250000	0.2355	0.162882735	0.601187021
0.0260333	0.245234	0.157467196	0.601489886
0.0268167	0.252613	0.150801918	0.600581291
0.0276000	0.259992	0.155800877	0.600581291
0.0286333	0.269726	0.162882735	0.603912806
0.0294167	0.277105	0.167256823	0.604821401
0.0302000	0.284484	0.162257865	0.603004211
0.0312500	0.294375	0.155384297	0.602095616
0.0320167	0.301597	0.162466155	0.602398481
0.0330667	0.311488	0.169964593	0.603307076
0.0338500	0.318867	0.166007084	0.603307076
0.0346333	0.326246	0.166215374	0.601489886
0.0356667	0.33598	0.161216415	0.600278426
0.0364500	0.343359	0.168089983	0.602095616
0.0372333	0.350738	0.174963551	0.604215671
0.0382667	0.360472	0.172672362	0.604215671
0.0390500	0.367851	0.169548013	0.601792751
0.0401000	0.377742	0.164549054	0.601792751
0.0408833	0.385121	0.173297232	0.604821401
0.0416667	0.3925	0.17912935	0.605124266
0.0427000	0.402234	0.17787961	0.603307076
0.0434833	0.409613	0.166631954	0.602701346
0.0442667	0.416992	0.171422622	0.604518536
0.0453000	0.426726	0.1780879	0.605729996
0.0460833	0.434105	0.174963551	0.605729996
0.0471333	0.443996	0.165590504	0.604821401
0.0479167	0.451375	0.169756303	0.605124266
0.0486833	0.458597	0.176421581	0.606335726
0.0497333	0.468488	0.183086859	0.606638591
0.0507667	0.478222	0.182461989	0.605427131
0.0515500	0.485601	0.169756303	0.603609941

Table 9- Tribometer Data Sample

Appendix O-Bearings, Gears and Belt Specification

Drilling Stage

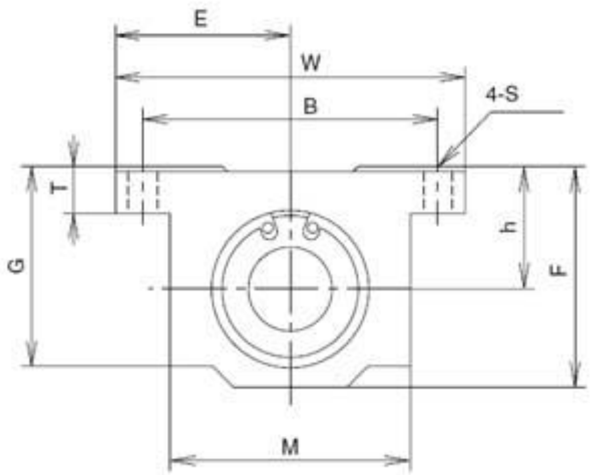
TWA-W Type: Slide Unit, Pillow Block
Made in Japan: NB Linear Systems
Nippon Bearing Linear Systems



Part Number	Shaft diameter inch	major dimensions inch								mounting dimensions			basic load rating		mass lbs
		h inch	E inch	W inch	L inch	F inch	T inch	G inch	M inch	B inch	C inch	S inch	dynamic C lbf	static Co lbf	
TWA 8WUU	1/2	.6870	1.000	2.000	3.500	1.250	.250	1.125	1.375	1.688	2.500	.156	370	580	.510

Sawing Stage Bearing

TWA Type: Slide Unit, Pillow Block
Made in Japan: NB Linear Systems
Nippon Bearing Linear Systems

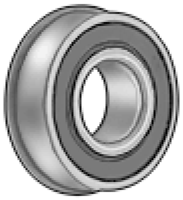


Part Number	Shaft diameter inch	major dimensions inch								mounting dimensions			basic load rating		mass lbs
		h inch	E inch	W inch	L inch	F inch	T inch	G inch	M inch	B inch	C inch	S inch	dynamic C lbf	static Co lbf	
TWA8UU	1/2	.6870	1.0000	2.0000	1.688	1.250	.250	1.125	1.375	1.688	1.000	.156	230	290	.248

1/2" Slide Unit Pillow Block (Inch Series), inner diameter(bore)= 1/2" (.500") inch dimensions with steel retainer, high accuracy grade linear bushings, series mainly used in the USA, NB brand (Nippon Bearing Linear Systems), made in Japan.

Ball and Roller Bearings

This product matches all of your selections.

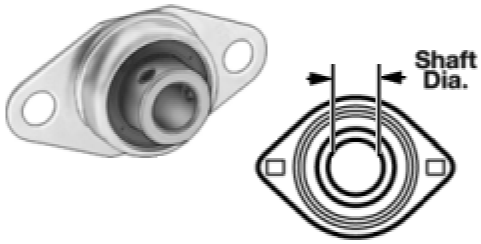


Part Number: 6384K363

Type	Ball Bearings
Ball Bearing Style	Flanged Double Sealed
Ball Bearing Type	General Purpose
System of Measurement	Inch
For Shaft Diameter	1/2"
Outside Diameter	1-3/8"
Width	1/2"
Flange Outside Diameter	1-1/2"
Flange Thickness	1/16"
ABEC Precision Bearing Rating	Not Rated
Dynamic Radial Load Capacity, lbs.	450
Dynamic Radial Load Capacity Range, lbs.	251 to 500 lbs.
Maximum rpm	1,000
Maximum rpm Range	250 to 3,000
Temperature Range	-20° to +250° F
Bearing Material	Steel
Seal Material	Plastic
Specifications Met	Not Rated
Note	Bearing comes greased.

Mounted Bearings

This product matches all of your selections.

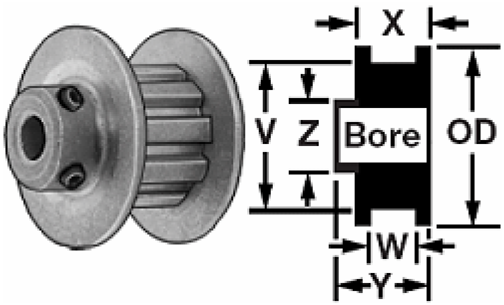


Part Number: 7208K51

Mounting Style	Flange Mount
Flange Mount Type	Standard
Type	General Purpose
Bearing Style	Ball
For Shaft Diameter	3/8"
Dynamic Radial Load Capacity, lbs.	580
Maximum rpm	3,000
ABEC Precision Bearing Rating	Not Rated
Housing Material	Steel
Steel Housing Material	Plain Steel
Bearing Material	Steel
Temperature Range	Up to +250° F
Bearing Construction	Double Sealed
Secures/Attaches With	Double Set Screw
Note	Sets screws included.

Pulleys for Belts

This product matches all of your selections.

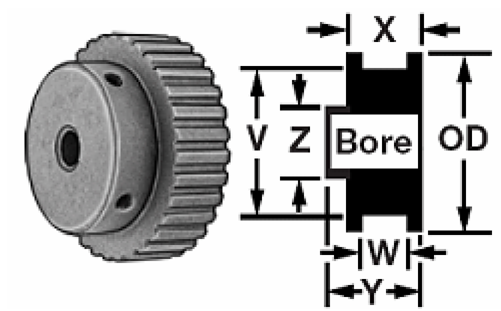


Part Number: 57105K22

Pulley Type	Drive Pulleys
For Belt Type	Timing Belt Pulleys
Timing Belt Series	XL Series
Number of Teeth on Pulley	24
Pulley Design	Solid
System of Measurement	Inch
For Timing Belt Width	1/4", 3/8"
Outside Diameter	1-3/4"
Bore Type	Finished Bore
Finished Bore Pulley Style	Standard
Bore Size (ID)	5/16"
W-Dimension	1/2"
X-Dimension	5/8"
Y-Dimension	7/8"
Z-Dimension	7/8"
V-Dimension (Pitch Dia.)	1.528"
Pitch	.2"
Pulley Material	Acetal Plastic with Aluminum Hub
Note	Includes set screws.

Pulleys for Belts

This product matches all of your selections.

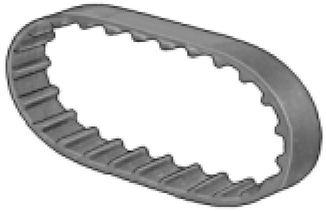


Part Number: 6495K733

Pulley Type	Drive Pulleys
For Belt Type	Timing Belt Pulleys
Timing Belt Series	XL Series
Number of Teeth on Pulley	72
Pulley Design	Solid
System of Measurement	Inch
For Timing Belt Width	1/4", 3/8"
Outside Diameter	4.564"
Bore Type	Finished Bore
Finished Bore Pulley Style	Standard
Bore Size (ID)	3/8"
W-Dimension	9/16"
X-Dimension	9/16"
Y-Dimension	1"
Z-Dimension	1-1/2"
V-Dimension (Pitch Dia.)	4.584"
Pitch	.2"
Pulley Material	Steel
Note	Not flanged. Includes set screws.

Belts

This product matches all of your selections.



Part Number: 6484K228

Form	Belts
Type	Timing Belts
Timing Belt Type	Single-Sided with Trapezoidal Teeth
Material	Rubber
Cord Material	Polyester
Number of Teeth	90
Outer Circle	18"
Belt Width	3/8"
Timing Belt Series	XL Series
Pitch	.2"
Trade Size	180XL
Color	Black
Specifications Met	Not Rated

Appendix P-Lead Screws and Linear Shaft

GRAINGER
FOR THE ONES WHO GET IT DONE

Catalog 401 | Find a Branch | Search

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Ball Screw, 0.500 In Dia, 48 In L, Steel

Power Transmission > Bearings > Precision Ball Screws

Precision Ball Screw, Ball Screw Dia 0.500 In, Lead 0.500 In, Right Hand Direction, Root Diameter 0.410 In, Length 48 In, Number of Starts 2, Carbon Steel Material, For Use With Ball Nuts 2LGH7, For Use With End Blocks 2LGL1

Grainger Item #	2LGF1
Price (ea.)	**$160.75**
Brand	THOMSON
Mfr. Model #	190-9096CTL48
Ship Qty. ?	1
Sell Qty. (Will-Call) ?	1
Ship Weight (lbs.)	2.5
Usually Ships** ?	1-3 Days
Catalog Page No.	211
Country of Origin (Country of Origin is subject to change.)	USA

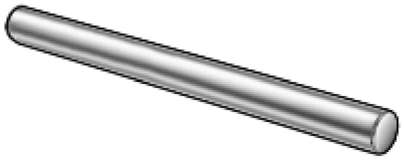
Enlarge Image

Tech Specs | Additional Information | Compliance & Restrictions | MSDS | Required Accessories | Optional Accessories | Alternate Products | Repair Parts

Item	Precision Ball Screw
Ball Screw Dia (In.)	0.500
Lead (In.)	0.500
Direction	Right Hand
Root Diameter (In.)	0.410
Length (In.)	48
Number of Starts	2
Material	Carbon Steel
For Use With Ball Nuts	2LGH7
For Use With End Blocks	2LGL1

Precision Shafts

This product matches all of your selections.

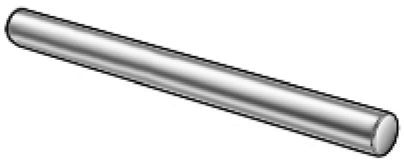


Part Number: 6061K73

Application	Linear Motion Shafts
Type	Shafts
Shaft Type	Shafts
System of Measurement	Inch
Material	Steel
Steel Type	AISI 1566 Steel
Finish	Plain
Surface Finish	12 rms
Hardness	Case Hardened
Minimum Hardness Depth	0.04"
Rockwell/Brinell Hardness	Rockwell C60
Outside Diameter	1/2"
Outside Diameter Tolerance	-0.0005" to -0.001"
Straightness Tolerance	0.002" per foot
Overall Length	48"
Ends	Chamfered
Specifications Met	American Iron and Steel Institute (AISI)
Note	Are precision ground for exacting diameter and straightness tolerances.

Precision Shafts

This product matches all of your selections.



Part Number: 6061K636

Application	Linear Motion Shafts
Type	Shafts
Shaft Type	Shafts
System of Measurement	Inch
Material	Steel
Steel Type	AISI 1566 Steel
Finish	Plain
Surface Finish	12 rms
Hardness	Case Hardened
Minimum Hardness Depth	0.04"
Rockwell/Brinell Hardness	Rockwell C60
Outside Diameter	1/2"
Outside Diameter Tolerance	-0.0005" to -0.001"
Straightness Tolerance	0.002" per foot
Overall Length	42"
Ends	Chamfered
Specifications Met	American Iron and Steel Institute (AISI)
Note	Are precision ground for exacting diameter and straightness tolerances.

Compatible Nut

Precision Acme Nuts & Flanges

This product matches all of your selections.

Part Number: 95072A145 $31.45 Each

Type	Round Nut
Material Type	Bronze
Finish	Plain
Thread Direction	Right Hand Thread
Start Type	Fast Travel Multiple Start
Acme Size	1/2"-10
Travel Distance Per Turn	1/2"
Nut Diameter	1.12"
Overall Length	.75"
Speed Ratio (Starts)	5:1
External Thread Size	.937"-16
External Thread Length	.50"
Hardness	70 to 126 Brinell
Load Capacity	1,300 lbs.
Specifications Met	Not Rated
Mounting Flange	95082A642
Compatible Threaded Rod	99030A704 (6-ft. length 1018 Carbon Steel); 98980A375 (6-ft. length Type 304 Stainless Steel)

Compatible Nut

Precision Acme Nuts & Flanges

This product matches all of your selections.

Part Number: 95072A420 $31.45 Ea

Type	Round Nut
Material Type	Bronze
Finish	Plain
Thread Direction	Right Hand Thread
Start Type	Fast Travel Multiple Start
Acme Size	1/2"-8
Travel Distance Per Turn	1"
Nut Diameter	1.12"
Overall Length	.75"
Speed Ratio (Starts)	8:1
External Thread Size	.937"-16
External Thread Length	.50"
Hardness	70 to 126 Brinell
Load Capacity	1,300 lbs.
Specifications Met	Not Rated
Mounting Flange	95082A642
Compatible Threaded Rod	99030A400 (6-ft. length 1018 Carbon Steel); 98980A183 (6-ft. length Type 304 Stainless Steel)

Appendix Q-Vibration Analysis

1 of 3

(1) Vibrational analysis

Because the natural frequency of the Paddle Maker is desired; and because of the machine being formed by several subsystems; namely: drilling station, sawing assembly and roller table, it was chosen to use Dunkerley's formula, to determine the systems first natural frequency.

$$\frac{1}{\omega_n^2} = \frac{1}{\omega_1^2} + \frac{1}{\omega_2^2} + \frac{1}{\omega_3^2} = \frac{1}{(\omega_{Table})^2} + \frac{1}{(\omega_{drill})^2} + \frac{1}{(\omega_{SAW})^2} = \frac{1}{(\omega_{system})^2}$$

where $\omega = \sqrt{\frac{K}{m}}$ so $\frac{1}{\omega_n^2} = \frac{m_1}{K_1} + \frac{m_2}{K_2} + \frac{m_3}{K_3}$

thus $$\omega_n = \left(\frac{1}{\frac{m_1}{K_1} + \frac{m_2}{K_2} + \frac{m_3}{K_3}}\right)^{(1/2)} = \omega_{system} \quad \text{(I)}$$

then the motors frequency is obtained by converting from RPM to rad/s.

if $\omega_n < \omega_{any\ motors}$ → no resonance

if not then vibration absorbers are to be used.

the Paddle maker was divided into three different subsystems: table; drilling station and sawing station; for all of these K and m is needed.

"Table" $m = 75$ lbs

Because the whole table is experiencing the same continuous load ($W_{sheet} \approx 40$ lb) then the spring coefficients (K) are in series the four legs are witnessing the same deflection thus they are in parallel

LEGS: $L_6 = 30''$

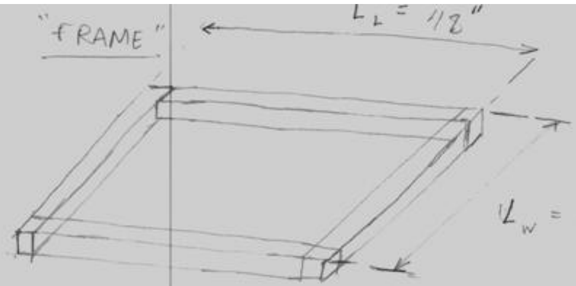
$r_2 = 0.07'$

$r_1 = 0.0571$

for a rod $K = \frac{EA}{L}$; the legs surface area is a annulus thus $K = \frac{\pi (r_2^2 - r_1^2) E}{l}$

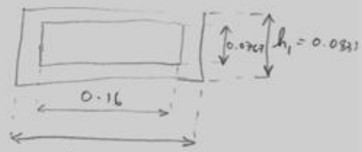
(2) "FRAME"

$L_L = 42''$



$L_W = 39''$

cross-sectional area



$b_1 = 0.1666$

$$I = \frac{b_1 h_1^3}{12} - \frac{b_2 h_2^3}{12} = 3.513 \times 10^{-6}$$

for (simply supported) $k = \dfrac{48EI}{L_1^3}$; for (fixed–fixed) $k = \dfrac{192\,EI}{L_1^3}$ ✓

we assume that every beam is fixed (worst case scenario)

DRILLING ASSEMBLY $m = 18$ lbs

$L_D = 42''$

here the support rods are considered to be fixed; and the lead screw is thought of as a free rod.

"SUPPORT RODS"

$k = \dfrac{192\,EI}{L_1^3}$ where $I = \dfrac{\pi}{4} r^4$

"LEAD SCREW"

$k = \dfrac{AE}{L}$ $r_{\text{LEAD SCREW}_{\text{Drill}}} = 0.25''$

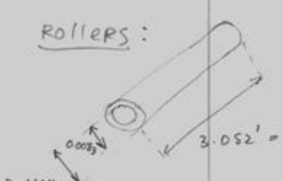
"SAW STATION" $m = 10$ lbs

$L_S = 45''$

saw station and drilling station analysis is the same, the only difference being the length "L". For both cases $r_{rod} = 0.25''$ $r_{\text{LEAD SCREW}_{\text{SAW}}} = 3/16''$

"round rod in torsion"

ROLLERS:



$$K_{eq} = \frac{\pi d^4 G}{32L} \text{ for}$$

thus for annulus $k_{roller} = \dfrac{\pi\, G\,(D^4 - d^4)}{32\, L_R}$

there're 9 rollers experiencing same deflection. thus they are in parallel

3 of 3

(3) thus the Dunkerley's formula (I)

$E = 30 \times 10^6$ psi, $G = 11.2 \times 10^6$ psi } steel

$$\omega_n = \omega_{system} = \left(\frac{1}{\frac{m_1}{K_1} + \frac{m_2}{K_2} + \frac{m_3}{K_3}} \right)^{(1/2)}$$

where :

$m_{table} = m_1 = 75$ lbs ; $m_{Drill\ station} = m_2 = 15$ lbs ; $m_{SAW\ STATION} = m_3 = 10$ lbs

$$\bullet \ \frac{1}{K_1} = \frac{1}{Keq_{table}} = \frac{1}{2(K_{FRAME_L})} + \frac{1}{4(K_{LEGS})} + \frac{1}{9(K_{Roller})} + \frac{1}{2(K_{FRAME_W})}$$

$$\frac{1}{K_1} = \frac{1}{2\left(\frac{192EI}{L_L^3}\right)} + \frac{1}{4\left(\frac{\pi(r_2^2 - r_1^2)E}{L_G}\right)} + \frac{1}{9\left(\frac{\pi G}{32 \cdot L_R}(D^4 - d^4)\right)} + \frac{1}{2\left(\frac{192\ E \cdot I}{L_W^3}\right)} \quad (II)$$

$$\bullet \ \frac{1}{K_2} = \frac{1}{Keq_{Drill\ station}} = \frac{1}{2\left(K_{SUPPORT\ RODS}\right)} + \frac{1}{\left(K_{LEAD\ SCREW}\right)}$$

$$\frac{1}{K_2} = \frac{1}{2\left[\frac{192 \cdot E\left(\frac{\pi}{4}(r^4)\right)}{L_D^3}\right]} + \frac{1}{\frac{EA}{L_D}} \quad (III)$$

$$\bullet \ \frac{1}{K_3} = \frac{1}{Keq_{SAW\ STATION}} = \frac{1}{2\left(K_{SUPPORT\ RODS}\right)} + \frac{1}{\left(K_{LEAD\ SCREW}\right)} = \frac{1}{2\left[\frac{192E\left(\frac{\pi}{4}r^4\right)}{L_S^3}\right]} + \frac{1}{\frac{EA}{L_S}} \quad (IV)$$

then substituting all known properties and values :

$K_1 = K_{Table} = 344.9$ lbf / ft

$K_2 = K_{Drill\ station} = 39.619$ lbf / ft

$K_3 = K_{SAW\ station} = 32.152$ lbf / ft

and so $\boxed{\omega_{system} = \omega_n \approx 1.009 \text{ rad/s}}$

* the table mover system including its stepper motor are excluded from this analysis since they are moving very slow and less than one revolution ; so it can be considered stationary.

then motors known RPM was found its correspondent ω (rad/s)

since 1 RPM = $2\pi/60$ rad/s

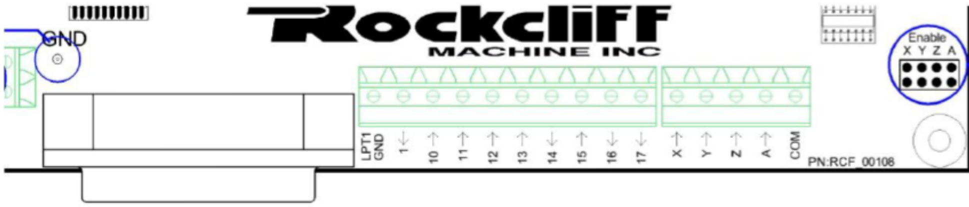
then

Motors	SPEED (RPM)	W (rad/s)
STEPPER (SAW ASSEMBLY)	950	99.484
STEPPER (DRILL-X axis)	950	99.484
STEPPER (DRILL-Y AXIS)	50	$\boxed{5.236}$
MOTOR (SAW ASSEMBLY)	2000	209.44
MOTOR (DRILLING STATION)	1200	[illegible]

therefore $\omega_{system} < \omega_{any\ motor}$

thus the machine should have no resonance.

Appendix R-Rockcliff Pin Assignment



AXIS ENABLE
X
Y
Z
A

DB25 CONNECTOR PIN ASSIGNMENT	
1	STROBE
2	X - AXIS - STEP
3	X - AXIS - DIRECTION
4	Y - AXIS - STEP
5	Y - AXIS - DIRECTION
6	Z - AXIS - STEP
7	Z - AXIS - DIRECTION
8	A - AXIS - STEP
9	A - AXIS - DIRECTION
10	INPUT
11	INPUT
12	INPUT
13	INPUT
14	OUTPUT
15	INPUT
16	OUTPUT
17	OUTPUT
18	GROUND
19	GROUND
20	GROUND
21	GROUND
22	GROUND
23	GROUND
24	GROUND
25	GROUND

INPUT / OUTPUT
LPT GND
1 STROBE - OUTPUT
10 INPUT
11 INPUT
12 INPUT
13 INPUT
14 OUTPUT
15 INPUT
16 OUTPUT
17 OUTPUT

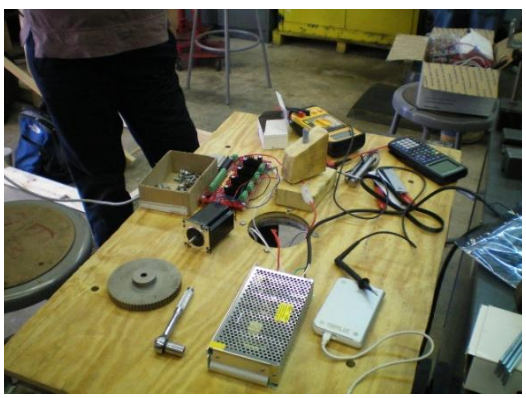
AXIS DISABLE
X
Y
Z
A
COM

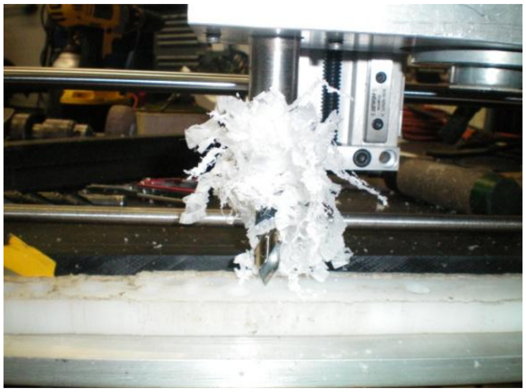
Appendix S-Machine Shop and Field Snapshots

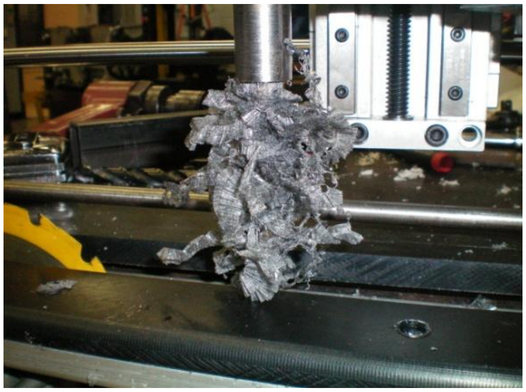

Mitutoyo

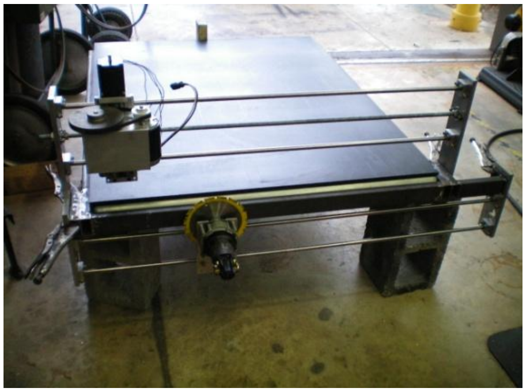

Mitutoyo

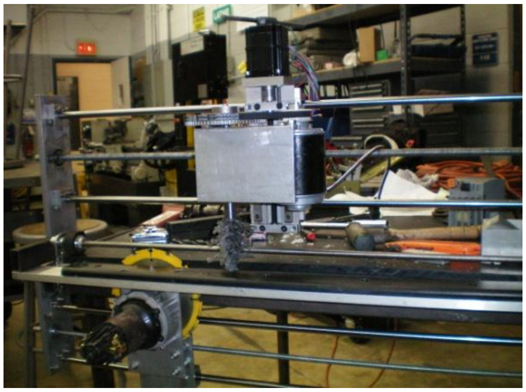

Mitutoyo



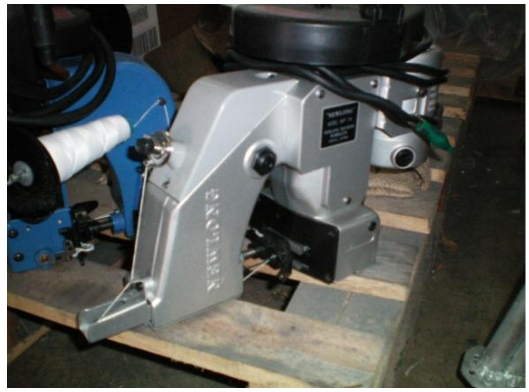








Appendix T-Snapshots Visit to Grainman Corporation



Appendix U-Electronics Set Up

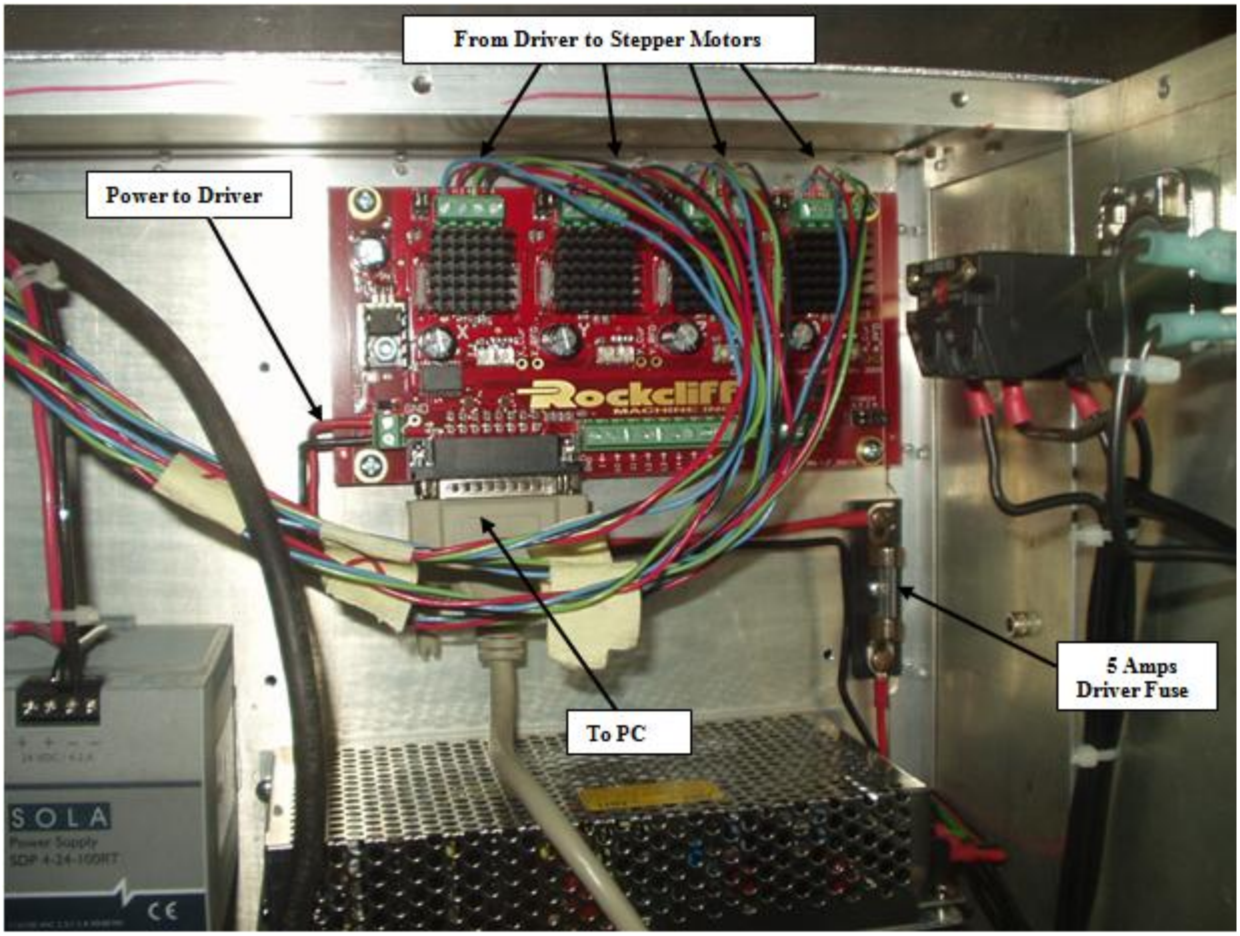


Figure 54-Electronic Controls

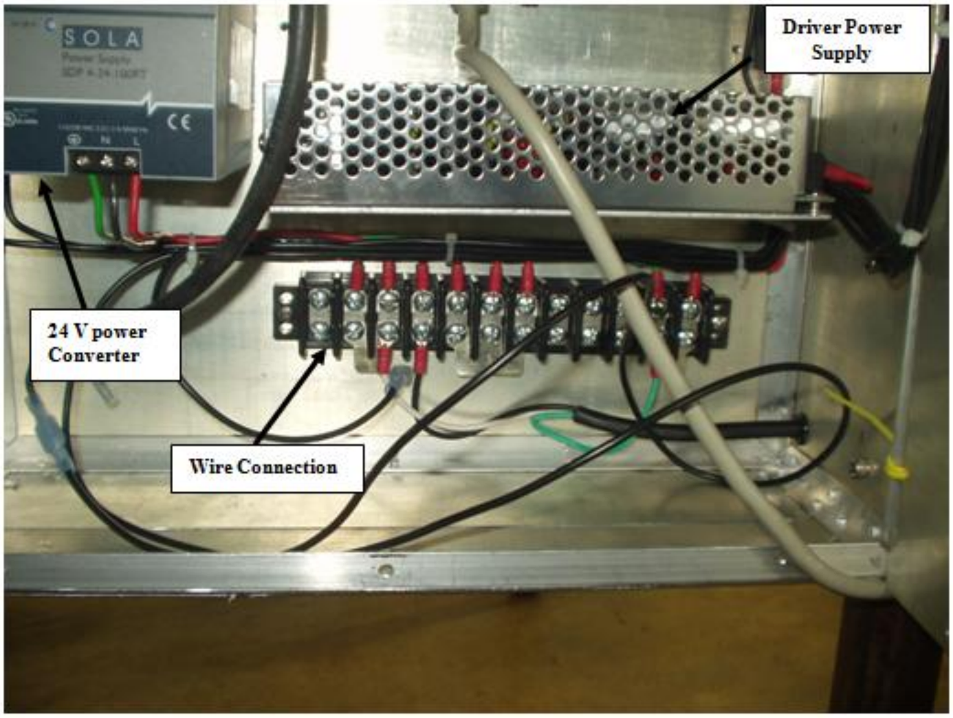


Figure 55-Power Supplies

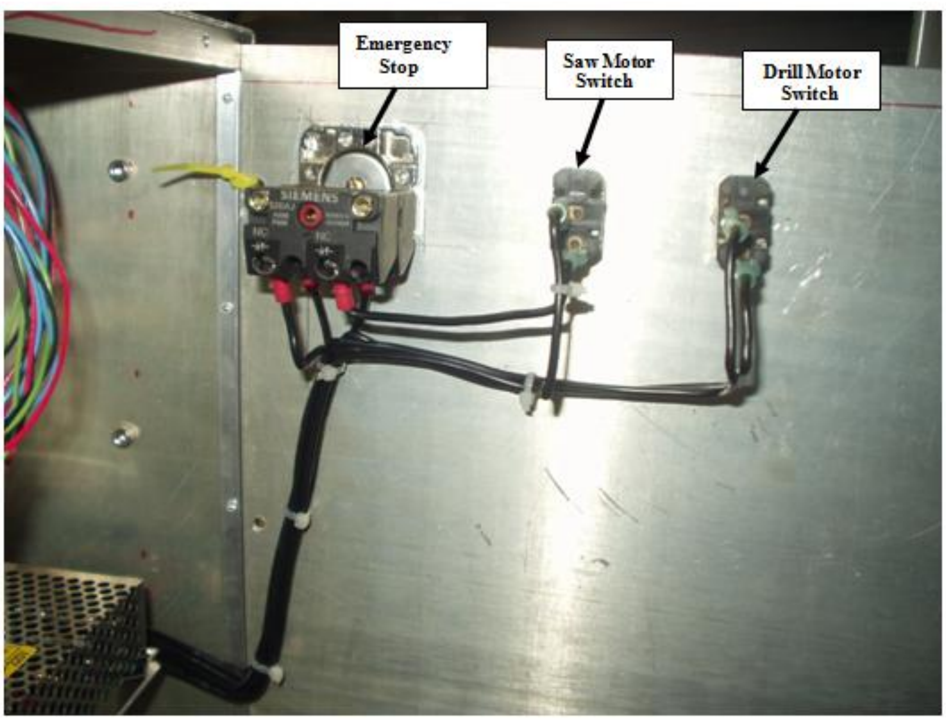


Figure 56-Emergency Stop and Controlling